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Research on Braking Process of High-speed Train with Aerodynamic Brake

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Abstract

The speed is higher, the kinetic energy is greater. In order to ensure the safety of a new generation train running in a high speed, it is necessary to research on its braking performance. In this paper, the braking force, running resistance, braking time, braking distance and the deceleration generated by the train with two kinds of braking wings were analyzed while the high-speed train was doing deceleration movement. And the results were compared and analyzed between the train with and without braking wing, and between the two kinds of braking wings. The results showed that the high speed train with braking wings made much contribution to the acceleration in the braking process, especially the train is in high speed.

Keywords: *high-speed train with aerodynamic brake, braking wings, braking force, deceleration*

1. Introduction

With the development of high-speed train, it’s running speed become higher and higher. In order to ensure the new generation of train with aerodynamic brake running in a high speed safety, a good braking wing must be selected.

There are many documents related to the research of high-speed train. Seung Pil Yoo presented the design and verification of a supervisory controller of the high-speed train [1]. Jaroslaw Guzinski presented an application of speed and load torque observers [2]. Q. Song presented an automated control scheme for high speed trains with combined longitudinal aerodynamics and tracking braking dynamics [3]. There are also many researches about the braking process of high-speed train research. XU Lixiu described the braking characteristics of various kinds of braking modes and the combinations of the braking modes for high-speed trains in German [4]. MA Dawei put forward several points which must be considered in transport organization of high speed trains, communication signals, track and bridge engineering design [5]. SONG Wei summarized the brake problem of different rail transport, including braking force, rotating mass coefficient and braking acceleration rate [6]. SHANG Guanwei studied the braking system of high-speed train above 250km/h, and analyzed the running resistance, braking force and braking distance of high-speed train. And proposed that the piecewise iteration model of braking mode curve for high-speed train based on curve theory of target distance mode [7].

The subject of this paper is high-speed train with aerodynamic brake, and braking wing is used to increase braking force on the high speed. Comparing to other braking ways, aerodynamic brake has many advantages, such as low maintenance, short transformation period for high-speed train and the retrofit design which is the relatively simple [8]. In this paper, the numerical simulation for high-speed train with aerodynamic brake is given and the

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importance of wings during reduction process is analyzed. Through the experiments, it is contrasted that braking force, running resistance, braking distance, the different kinds of braking wings, and deceleration of with and without braking wings. Thus it is concluded that braking wings play an important role in the high speed braking process.

This paper is structured as follows. In section 2, High-speed train braking basic theory is introduced. In section 3, the high-speed train model for brake research is introduced. In section 4, simulation experiment for high-speed train speed reduction is done. The analysis of experimental results is summarizingd in Section 5. Lastly, the conclusions are obtained in section 6.

2. Basic Theory

2.1. Running Resistance of High-speed Train

High-speed train with aerodynamic brake produces resistance ω which includes basic resistance ω_0 and additional resistance ω_1 .Additional resistance ω_1 including ramp resistance, tunnel resistance and so on. However the research environment should be considered to linear and gentle way. ω_1 can be neglected. ω_0 is the sum of other resistance(include frictional resistance and air resistance), which always exists in the operation process in any case [7].

So the resistance $\omega = \omega_0$ CRH(Motor train unit)units' basic resistance is mainly affected by train running speed v^2 , and this paper studies CRH3 emus type, basic resistance according to the formula is:

$$\text{CRH3: } \omega = \omega_o = (0.79 + 0.0064v + 0.000115v^2)M \tag{1}$$

M : Quality of high-speed train.

v : Train running speed.

2.2. Breaking Force for High-speed Train with Aerodynamic Brake

For high-speed train with aerodynamic brake, its air resistance is divided into resistance produced by braking wing and high-speed train body. Due to the resistance coefficient is defined as:

$$C_d = \frac{F_d}{\frac{1}{2}\rho v^2 S} \tag{2}$$

$$F_d = \frac{1}{2}\rho v^2 S C_d \tag{3}$$

Thus we can get:
S : Train positive projection area.
ρ : Air density.
v : Train running speed.

In the numerical modeling process, the C_d can be got by formula (2) and the aerodynamic drag can be calculated by formula (3). Through the aerodynamic drag, deceleration caused by the wing can be calculated.

According to the computing results, the ratio of resistance produced by the wings in general resistance can be worked out. Compare the resistance generated by the high speed train with and without braking wings, the influences of the braking wings can be find out [9].

2.3. CFD

Computational fluid dynamics, usually abbreviated as CFD, is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions. With high-speed supercomputers, better solutions can be achieved. Ongoing research yields software that improves the accuracy and speed of complex simulation scenarios such as transonic or turbulent flows. Initial experimental validation of such software is performed using a wind tunnel with the final validation coming in full-scale testing, *e.g.,* flight tests.

2.4. UDF

Fluent is used for the numerical simulation of high speed train with aerodynamic brake in this paper, which is a popular international commercial CFD software package. It can simulate the complex flow calculation problem, simulation flow, heat transfer and chemical reaction of physical phenomena problem and so on.

At the same time, Fluent can support high performance computer parallel environment to solve the fluid problem for high-speed train. From the user demand perspective, Fluent uses different discrete format and numerical method to solve all areas of complicated problem stability and precision, to achieve the best combination according to various complicated flow phenomena[10, 11] .

Fluent can identify the C/C++ function called UDF. In this paper, an UDF function is programed to do a better imitation for high-speed train braking process in different speed and to get an accurate result of the influence of the wing. UDF function has two different modes for compiling which are explain mode and compilation mode. Because that the UDF program is short in this paper, so we adopt the explain mode to run quickly.

3. Train Model

3.1. Head of Train Model

This train model on mesh is generated by the ANSYS ICEM CFD. The three models use a hybrid grid method to partition the area. The head of high-speed train detailed diagram is showed below.

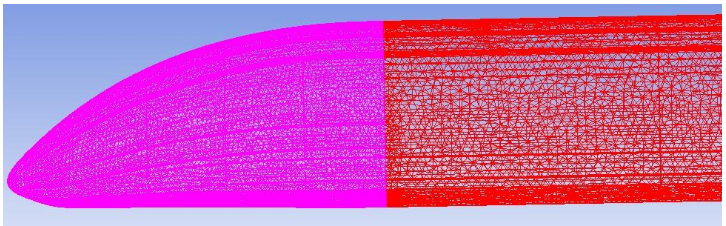

Figure 1. Head of Train Model

The three models, which are the high speed train without braking wings and with two different shapes of braking wings, are all like this model showed in Figure 1. They are generated 7.9 million grid units.

3.2. 8-train Model

This paper proposed 8-train model based on CRH3 which is a kind of high-speed train whose highest speed is 450km/h. The research object is high-speed train with bent braking wing model, with straight braking wing model and without braking wing model. The braking wings are distributed on the top of the train, and they are set as the researches we done before.

The 8-train model is showed in Figure 2 and Figure 3 respectively:

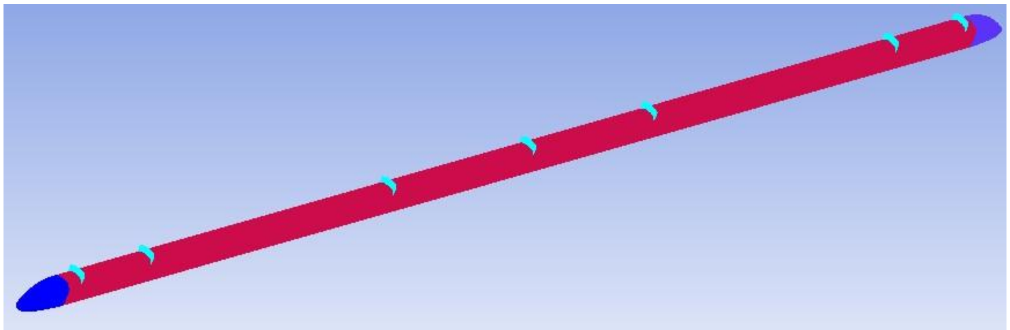

Figure 2. High-speed Train with Braking Wing

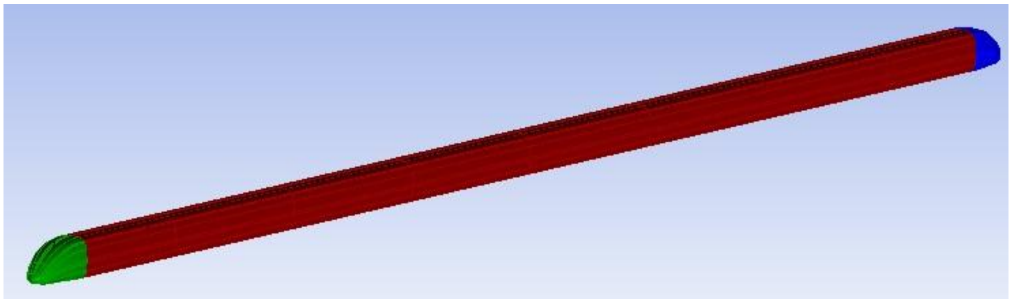

Figure 3. High-speed Train without Braking Wing

3.3. Braking Wing

This paper chose two shapes of braking wing, one is straight and the other is bent. They are showed in Figure 4 and Figure 5 below.

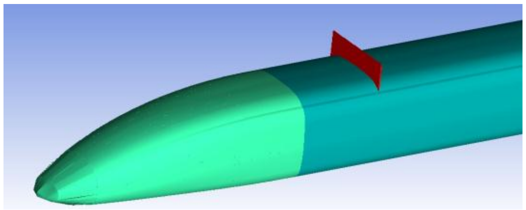

Figure 4. Straight Braking Wing

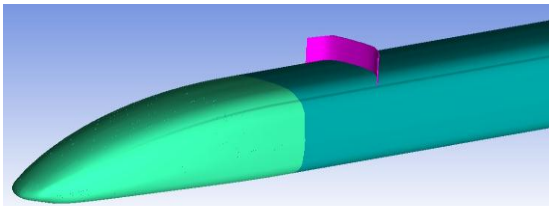

Figure 5. Bent Braking Wing

In Figure 4, the braking wing is straight. In Figure 5, the braking wing is bent. And the size of the bent braking wing's arc is not very big for both the limit of installation and the thickness of the braking wing. In order to compare the braking forces they generated conveniently, the projected area with the wind of the two kinds of braking wing is same.

4. Experiment

4.1. Experiment Environment

The hardware environment of the parallel computing is eight 2.4GHz Intel quad-core processors and 32G memory. And the software environment is Windows 7, ANSYS ICEM CFD 12.0 and fluent 6.3.26.

4.2. Experiment Process

The experiment process flowchart is showed in below.

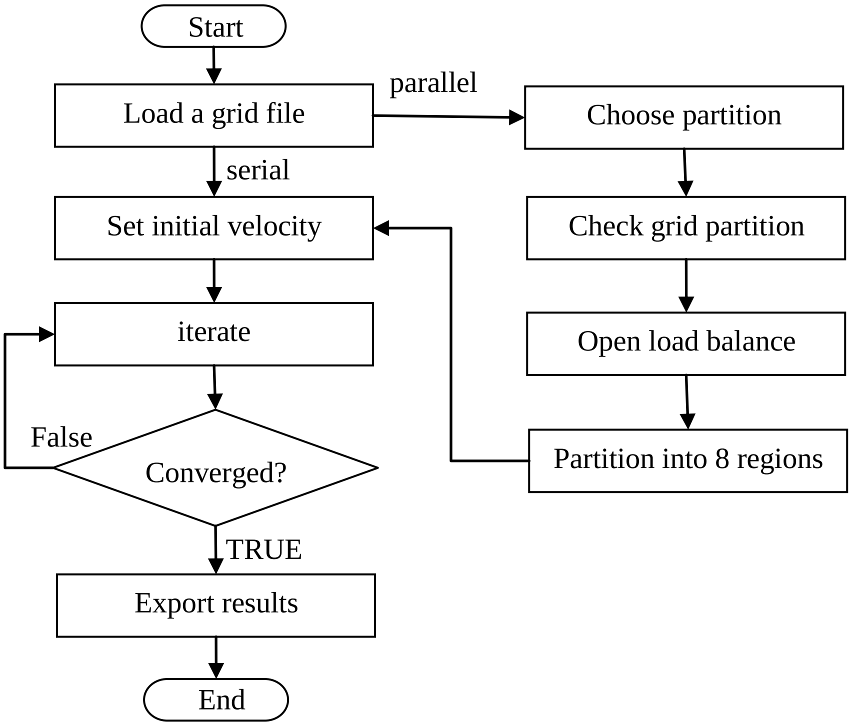

Figure 6. Experiment Process Flowchart

As Figure 6 showed, a grid file is loaded firstly. Parallel computing can speed up the computing progress. Then some additional work should be done, which are choosing partition, checking grid partition, opening load balance and partitioning into 8 regions.

The initial velocity of train model, bound conditions and a iterate number to start iterating are set. When the results are converged, it is done.

4.3. UDF Program

The initial velocity v_0 and acceleration are defined by UDF program as Figure 7 showed below.

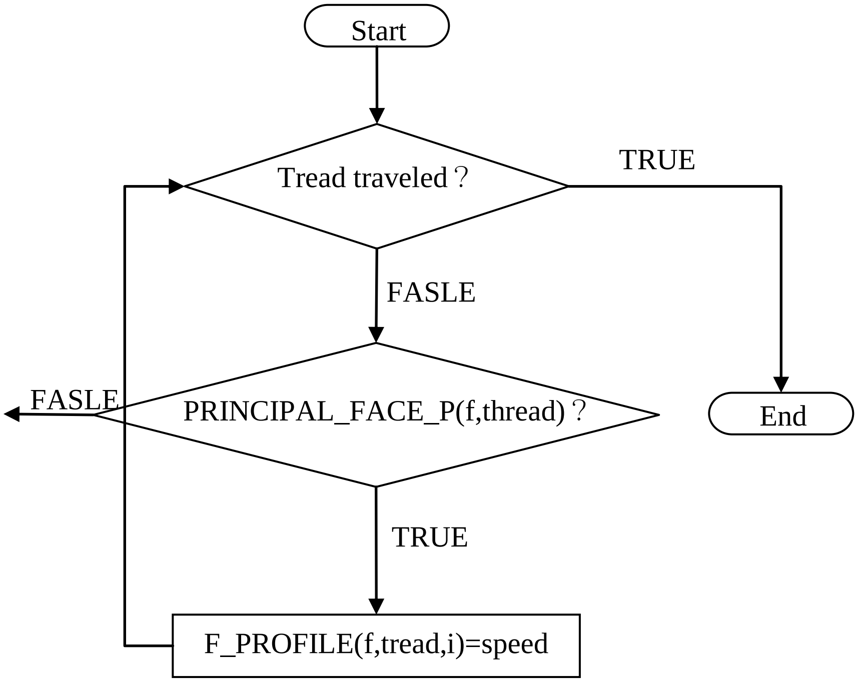

Figure 7. UDF Program Flowchart

Through this UDF program flowchart, we can set a constant v_0 as initial velocity and a constant acceleration. Then we can simulate braking of high-speed train with aerodynamic brake.

5. The Analysis of Experimental Results

5.1. Initial Velocity and Basic Resistance

The high-speed train type is CRH3 in this paper, 8-train mode for experiment is selected. The basic force power is calculated through the initial velocity and formula (1). When the train speed become slower, the force power will change. The results are showed in the Table 1 and Figure 8 below.

Table 1. Initial Velocity and basic Resistance Relationship Diagram

V_0	450	425	400	375	350	325	300	250	200	150	100
ω	5392	4856	4350	3872	3424	3003	2612	1916	1334	868	516

V_0 : Initial velocity
ω : Basic resistance
The train speed and basic resistance relationship diagram is showed in Figure 8 below.

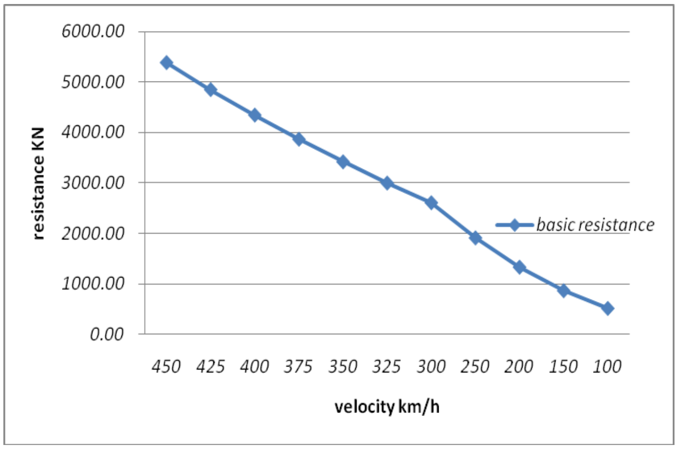

Figure 8. Speed and Resistance Relationship

Figure 8 shows clearly that an analogous liner relationship between train speed and resistance. And when the train speed becomes lower, the resistance becomes smaller. The change of the basic resistance as the speed of high speed train makes the braking progress complicated.

5.2. Aerodynamic Acceleration and Braking Time

The aerodynamic acceleration and braking time relationship diagram is showed in Figure 9 below.

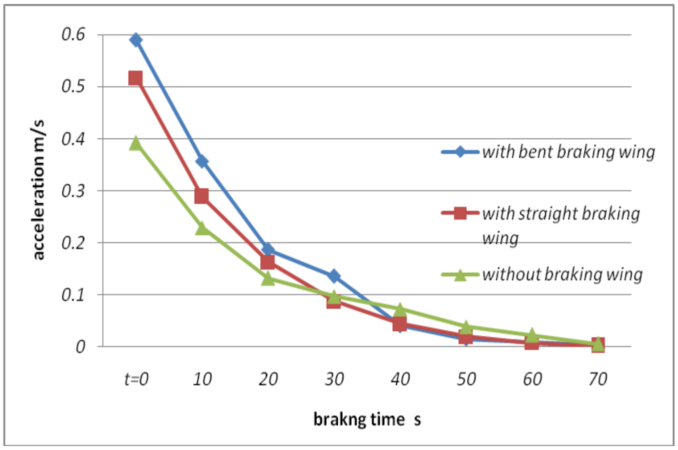

Figure 9. Acceleration to the Time

The Figure 9 tells that the acceleration with braking wing is much greater than the one without braking wing in the first 30 seconds. And 30 seconds later, the effect of the braking wing will be vanished.

In addition, the shape of braking wing makes contribution to the acceleration. In the first 40 seconds, the acceleration with bent braking wing is greater than the one with straight braking wing. And the two kinds of braking wing make a similar contribution after 40 seconds. The acceleration with straight braking wing changes more smoothly than the one with bent braking wing.

5.3. Acceleration and Braking Time

As mentioned above, the acceleration and braking time could be calculated. The relationship between them is showed in Figure 10 below.

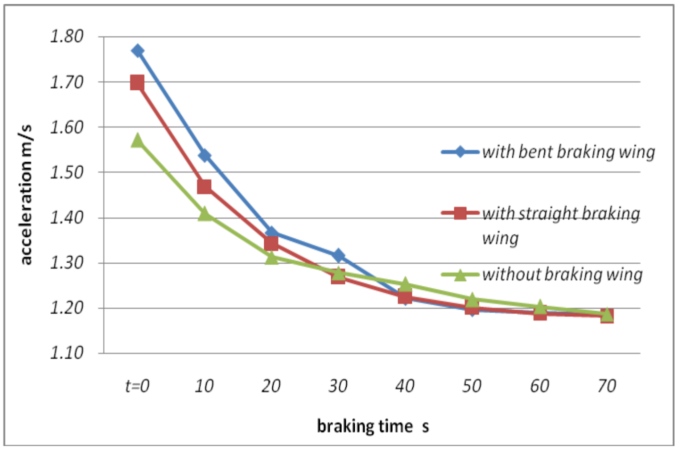

Figure 10. Acceleration-braking Time

In the first 28 seconds, the change range of the air acceleration with braking wings is larger than the one without braking wings in Figure 10 showed.

And the acceleration with bent braking wings is a little larger than the one with straight braking wing in the first 40 seconds. After 40 seconds, the two braking wing make same contributions.

From Figure 10, it also can be showed that the acceleration produced by air resistance is relatively small and the shape of braking wing has little help on the air acceleration.

5.4. Resistance Produced by Braking Wing

The resistance produced by braking wing and velocity relationship diagram is showed in Figure 11 below.

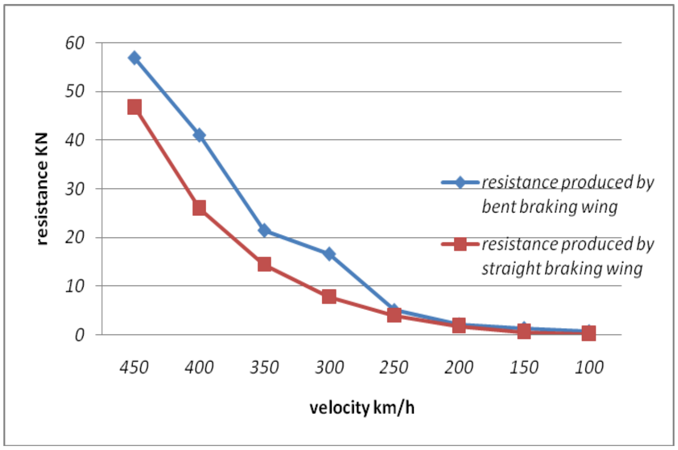

Figure 11. Resistance Produced by Braking Wing

From Figure 11, it can be showed that along with the high-speed train running speed decreasing, resistance produced by braking wing become lower. When the high-speed train speed decreases below 200 km/h, the resistance produced by braking wing will even trend to zero.

And the resistance produced by bent braking wing is a little greater than the one produced by straight braking wing, when the speed of train is faster than 250 km/h. But the gap is not obvious.

So it is obvious that, the braking wing can give a good help on braking when train speed is high; but, it does not give help on braking of low-speed train. And the shape has a little help on braking, whenever the speed is high or low.

5.5. Braking Force and Braking Time

The braking force with braking wing includes the basic resistance, the additional resistance and the resistance produced by braking wing.

The braking force without braking wing is made up of the basic resistance and the additional resistance.

The braking force and braking time relationship diagram is showed in Figure 12 below.

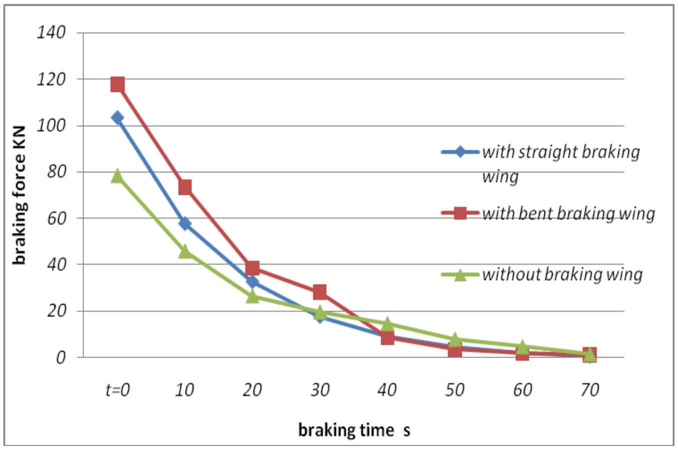

Figure 12. The Braking Force and Braking Time Relationship Diagram

The Figure 12 shows the different braking force changing process according to the time between the high-speed train without braking wing, with bent braking wing and with straight braking wing.

And it can be observed that the braking force with braking wing is greater than the one without braking wing in the first 30 seconds.

In the first 40 seconds, the braking force with bent braking wing is a little greater than the one with straight braking wing.

After 30 seconds, the braking fore with straight braking wing becomes smaller than the one without braking wing.

Then after 36 seconds, the braking force with bent braking wing becomes smaller than the one without braking wing.

After 40 seconds, the braking force with straight braking wing is equal with the one with bent braking wing.

In addition, we can see that the braking force with straight wing and the one without braking wing change more smoothly than the braking force with bent braking wing does.

5.6. Braking Time and Initial Velocity

During braking process, Air resistance occupies only a small part of the running resistance ω_0 .So through formula (1) we can calculate the running resistance.

$$a = F/M = \omega/M \qquad (4)$$

Through formula (4) can calculate acceleration, and the braking time of high-speed train can be calculated. The result can be showed in Table 2:

Table 2. Braking Time of High-speed Train

Velocity (km/h)	High-speed train with bent braking wing	High-speed train with straight braking wing	High-speed train without braking wing
450	97.68	97.84	98.62
425	95.14	95.29	96.03
400	92.35	92.45	93.14
375	89.23	89.28	89.92
350	85.69	85.71	86.31
325	81.66	81.67	82.22
300	77.08	77.05	77.56
250	66.50	66.41	66.84
200	53.05	52.95	53.27
150	43.19	43.12	43.27
100	27.10	27.08	27.13

As above, the initial velocity and braking distance relationship diagram of the braking of high-speed train with bent braking wing, one with straight braking wing and another without braking wing can be calculated. The diagram is showed in Figure 13 below.

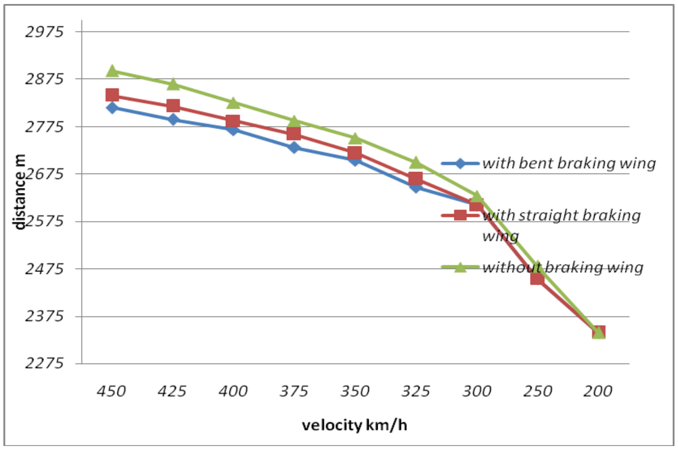

Figure 13. The Braking Distance and Velocity Relationship Diagram

Through Table 2 and Figure 13, it can be concluded that when the speed is greater than 300 km/h, the braking distance of high-speed train with braking wing are shorter than the one without braking wing.

When the train speed is less than 300 km/h, the difference of braking time and braking distance between the three kinds of high-speed train is not obvious.

And when the train speed is greater than 300 km/h, the braking distance with bent braking wing is a little shorter than the one with straight braking wing. Especially, the braking distance with bent braking wing becomes equal with the one with straight braking wing, while the speed is less 300 km/h.

Through the above analysis can be concluded that braking wing have obvious braking effect when the speed of high-speed train is high, but it is not obvious between bent braking wing and straight braking wing.

6. Conclusions

The braking force results generated by the aerodynamic braking high-speed train without wing, one with bent wing and another with straight wing are compared.

Through the experiment, it is obvious that the braking force from the two wing models is bigger in high speed than the one without braking wing. And the shape makes a little help in high speed. But the braking wing has little help while the train speed is low, no matter the bent braking wing or straight braking wing.

The braking force is biggest at the beginning of the braking process. After that, with the train becoming slower, the braking force and accelerated speed become less and less until the train coming to a full stop.

As a result, the wing is especially useful in emergency braking due to the beginning braking force, but the shape of braking wing has little help on braking. It is valuable for further research in high-speed train with aerodynamic braking.

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