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OPTIMIZATION OF THE AUXILIARY STOPPING AREA PLANNING IN THE MIDDLE-TO-HIGH SPEED MAGLEV

Background: The Auxiliary Stopping Area (ASA) is the special section that possesses power supply rail and personnel evacuation facilities, whose quantities and locations in a line are of great significance to reduce construction cost and improve transportation efficiency for the middle-to-high speed maglev.

Aim: This paper focuses on optimizing the length and location of the ASA for the middle-to-high speed maglev system to improve the robustness of maglev line.

Methods: Two evaluation indexes which reflect the ASA restricts on the train operation process was proposed. A model for optimizing the setting of the ASA is constructed, and solved by the genetic algorithm.

Results: The result of numerical examples shows that the proposed method can effectively improve the performances of the ASA.

Conclusion: This paper proposed two indexes to reflect the impact of station settings on train operations, which provides a method to optimize the ASA from qualitative optimization to quantitative optimization.

Keywords: the middle-to-high speed, maglev, line optimization, quantitative analysis, auxiliary stopping area, ASA, genetic algorithm

1. INTRODUCTION

As from January 1, 2018, there are four commercial operations of Maglev line in the world was built, and maglev has received more and more attention in China [1]. Compared with the wheel-rail system, the maglev has some excellent characteristics, such as smaller turning radius, lower noise, stronger climbing ability and lower maintenance cost [2]. The maglev system includes three-speed grades: low-to-middle speed maglev $\leq$ 100 km/h, middle-speed maglev $\leq$ 200 km/h and high-speed maglev $\leq$ 400 km/h. At present, except for the low-to-middle speed maglev uses short stator induction linear motor technology [3], the other two all take the long stator synchronous linear motor technology [4, 5]. Therefore, the middle-speed maglev and high-speed maglev are similar inline settings. In this paper, the middle-to-high speed maglev is used to represent the middle-speed maglev and high-speed maglev.

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Generally, the safety operation of the middle-to-high maglev train needs to satisfy the following five-speed curve limits [5, 6]. The location and length of the ASA will affect the speed limit area in case the other line parameters were determined because only the ASA and station were installed with Power Rail (PR). The function of PR enables the maglev train to run again after it stops [7]. However, the ASA cannot cover all line because of the construction cost. Therefore, it is a dramatic significance to reasonably arrange the location and length of the ASA with the goal that guaranteed safe operation and low cost.

At present, some researchers mainly focus on optimizing the operating strategies of the maglev train which the location and length of the ASA were determined [8, 9]. However, when the bottlenecks of operation were considered during the design of the ASA, the implementation of operational strategies will be more feasible. A simulation optimization method was built by Bian [10], but no specific optimization goals were given by him, just optimize the ASA through qualitative judgment. So, in this paper, the restrictions of the ASA on the train operation process was analyzed in order to give a quantitative model.

The remainder of this article is organized as follow. **In Section 2**, the concept of the ASA was introduced, and the two evaluation indexes which reflect the ASA restricts on the trajectory planning was proposed. A model for optimizing the setting of the ASA is constructed, and the genetic algorithm is built to solve this model in **Section 3**. Numerical examples are given to validate the proposed methods in **Section 4**. Finally, **Section 5** gives the conclusion of this paper.

2. CONCEPTUAL ILLUSTRATION

In this section, the impact of the ASA was introduced, and two evaluation index was put forward to quantitatively describe the impact of the ASA on the train operation process.

2.1 The impact of the ASA

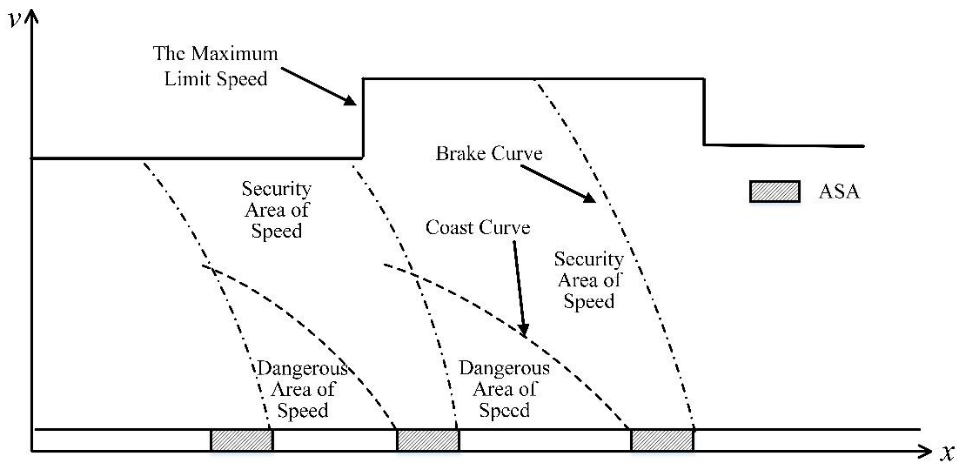

Fig 1. The impact of the ASA

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Safe operation is a most important goal for every per transport system. Due to the operating mechanism of the MHSM (middle-to-high speed maglev), it has created a safety concept of "safe parking". Safe parking means that the maglev can park in the designated area which calls ASA in any condition including run interference, malfunction or emergency situation.

The suspension and guiding of the MHSM are active control. The energy of the suspension device, guide device, and emergency braking system are root in the vehicle power supply system. The vehicle power supply system is composed of two part which including battery and linear generator of the vehicle. Then, the vehicle power supply system will choose one as a power supply approach according to the speed of maglev. When the speed of maglev is lower than the set speed (high-speed maglev is 80 km/h and middle-speed maglev is 100 km/h), the vehicle power supply system is the battery of the vehicle. When the speed of maglev is super than the set speed, the vehicle power supply system is the linear generator of the vehicle. In an unusual situation when the power of traction system is interrupted, the battery should guarantee the maglev continue to stay in suspension and braking. If the battery cannot be charged before the battery is exhausted, the maglev will not be able to levitate again. Therefore, to ensure the maglev have enough energy to levitate in a special situation, a couple of the ASA has been set in the interstation. Moreover, to ensure the passenger can evacuate the scene, the personnel evacuation facilities also be set in the ASA.

As shown in Fig. 1, the train should operate in the security area of speed to guarantee the safety.

2.2 Quantitatively describe the impact of the ASA

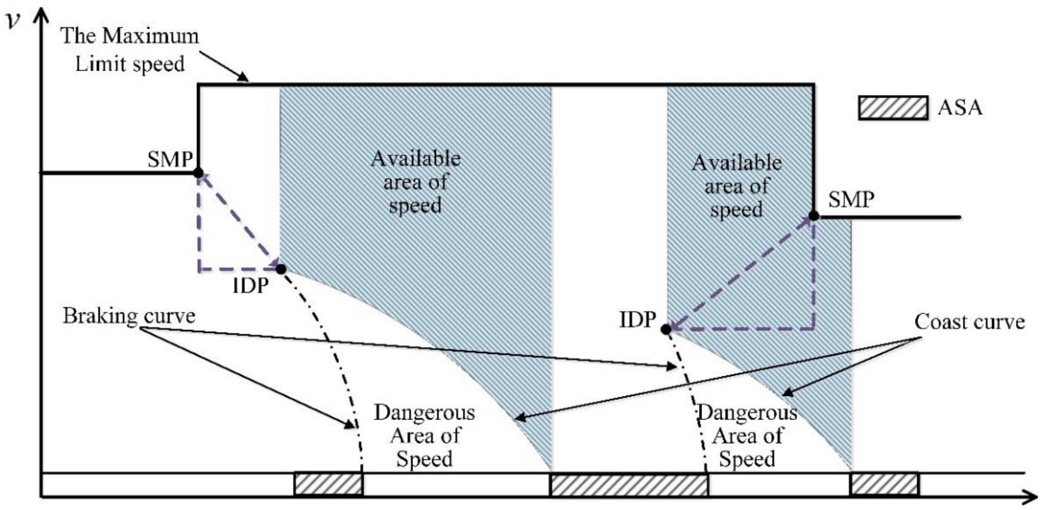

Fig. 2. Quantitatively describe the impact of the ASA

In this paper, the maximum limit speed is assumed to be known, which also indicated that the switching point of the maximum limit speed (SMP) was

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determined. From the section 2.1, the maglev train should keep them operating in the security area of speed which was formed by the maximum limit speed, coast curve, and braking curve. The intersection of the braking curve and coasting curve was denoted as IDP.

Two quantification criteria which reflect the restrictions of the ASA on maglev train operation are discussed:

1. Available area of speed

As shown on the Fig. 2, the available area of speed is constructed by the maximum limit speed and coast curve. The smaller available area of speed is, the less selective speed can the train choose. Therefore, the available area of speed is taken accounted as an evaluation index for the impact of the ASA.

2. The Euclidean distance between the IDP and SMP

Relying solely on the index of the available area of speed is unable to meet the robustness of the operation because the train speed will also be fewer options when the IDP is closer to SMP. Thus, the Euclidean distance between the IDP and SMP is considered as the second evaluation index for the impact of the ASA.

3. METHODOLOGY

A model for optimizing the setting of the ASA was formulated considering the two evaluation index, and a genetic algorithm also was built to solve the model.

3.1 The optimization model of the ASA

Table 1. Basic variables

Symbol	Description
L	The length of the inner-station
L_A	The total length of the ASA
$L_{\min}$	The minimum length of the ASA
M	The number of the ASA
x	The point of the location
m	The index of the ASA, and $m \in [1, M]$.
x_m^{start}	The starting point of the m th ASA
x_m^{end}	The endpoint of the m th ASA
P	The number of the IDP
p	The index of the IDP, and $p \in [1, P]$
x_p	The location of the p th IDP
v_p	The speed of the p th IDP
C	The number of the SMP
c	The index of the SMP, and $c \in [1, C]$

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Symbol	Description
x_c	The location of the c th SMP
v_c	The speed of the c th SMP
r	The cost of the ASA per meter

The minimum length of the ASA is determined, so the every ASA's length need to satisfy the Eq. (1.1):

$$x_m^{end} - x_m^{start} \geq L_{\min} \qquad \forall m \in [1, M] \tag{0.1}$$

Due to reflect the relationship of different ASA on the line, we built the constraint as Eq. (1.2).

$$x_m^{end} \leq x_{m+1}^{start} \tag{0.2}$$

The total length of the ASA is limited by the length of inner-station, so:

$$\sum_{m=1}^{M}\left(x_m^{end} - x_m^{start}\right) = L_A \leq L \tag{0.3}$$

In here, we assume the coast curve and braking curve is determined. When we know the location of the ASA, we can calculate every IDP via the coast curve and braking curve.

From the Section 2, we know that the object goal function includes three aspects.

1. The available area of speed

We denote $p_m \left(p_m \in [1, P]\right)$ is the index of the IDP which is the closest location among all the IDP to the m th ASA, and the location also is before the m th ASA.

$$p_m = \left\{ p : \min\left(x_m^{start} - x_p\right), \forall p \in [1, P] \right\} \tag{0.4}$$

The function of the maximum speed is $f^{\max}(x)$, and the $f_m^c(x)$ means the coast curve of the m th ASA. Owing to the coast curve is a non-linear function, so we reference the principle of calculus to divide the area into a small rectangle, and every length of a rectangle is Δx_m for the m th ASA's area. Δx_m can be calculated as Eq. (1.6), and Δx is the distance span which is determined.

So the available area of speed f^a can be calculated as Eq. (1.5).

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$$f^a = \sum_{m=1}^{M} \left(\sum_{q_m=0}^{Q_m} 1 \Big/ \left(\begin{array}{l} \left(\left(f^{\max}(x_{p_m} + q_m \Delta x_m) - f_m^c(x_{p_m} + q_m \Delta x_m) \right) \right. \\ \left. + \left(f^{\max}(x_{p_m} + (q_m+1)\Delta x_m) - f_m^c(x_{p_m} + (q_m+1)\Delta x_m) \right) \right) \\ * \Delta x / 2 \end{array} \right) \right) \quad (1.5)$$

The number of the rectangle indicated as Q_m, which can be calculated by Eq. (1.7).

$$\Delta x_m = \begin{cases} \Delta x & q_m < Q_m \\ \left(x_m^{start} - x_{p_m} \right) - \left(Q_m - 1 \right) \Delta x \end{cases} \quad (0.5)$$

$$Q_m = \left\lfloor \left(x_m^{start} - x_{p_m} \right) / \Delta x \right\rfloor \quad (0.6)$$

$\lfloor \bullet \rfloor$ is the symbol of down to the nearest integer.

2. The Euclidean distance between the IDP and SMP

We assume $c_p \left(c_p \in [1, C] \right)$ is the index of the SMP which is the closest location among all SMP to the p th IDP, so:

$$c_p = \left\{ c : \min \left| x_p - x_c \right|, \forall c \in [1, C] \right\} \quad (0.7)$$

Because the shorter of the distance between the SMP and IDP, the larger of the speed area for the maglev train. Thus, the concept of inverse function is considered in the model, so the Euclidean distance can be acquired by Eq. (1.9).

$$f^b = \sum_{p=1}^{P} \frac{1}{\sqrt{\left(\left(x_{c_p} - x_p \right)^2 + \left(v_{c_p} - v_p \right)^2 \right)}} \quad (0.8)$$

From above, the objective function is Eq. (1.11), and α is the weights of f^b.

$$\min Z = f^a + \alpha f^b \quad (0.9)$$

3.2 The genetic algorithm to optimize the ASA

Owing to the variables x_m^{end}, x_m^{start} cannot be expressed directly in the f^a, f^b, which cause the object function is non-close-form. So, in this paper, we

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built a genetic algorithm to solve the model.

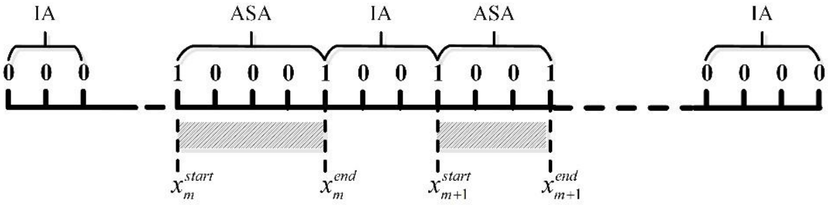

Fig 3. Chromosome representation of the setting of the ASA

We divide the inner-station into a small segment. As an illustration, Fig.3 shows that we mark up the split point as 1 or 0, and the span between a pair of 1 which does not contain 0 indicates that there exists an ASA, and the number of the segment for the m th ASA is c_m. Thus, by exchange, the values of the split point, a series of ASA which ranks in order will be acquired. There will exist interval area (IA) between two ASA, and the number of IA is $(M+1)$, and $d\left(d \in [1, M+1]\right)$ is the index of IA. The number of the segment for the d th IA is denoted as c_d.

Subject to constraints Eq. (1.1)~Eq. (1.3), the method which transfers the binary variable to locations of the ASA was proposed.

(1) Calculate the length of the m th ASA.

$$x_m^{end} - x_m^{start} = L_{\min} + \left(\frac{c_m}{c_{\min}} - 1\right)\left(L_A - ML_{\min}\right) \Big/ \sum_{m'=1}^{M}\left(\frac{c_{m'}}{c_{\min}} - 1\right) \qquad (0.10)$$

$$c_{\min} = \min\left\{c_m : m \in [1, M]\right\} \qquad (0.11)$$

$c_{\min}$ is the minimum value among c_m.

(2) Calculate the length of the d th IA.

The length of d th IA is represented by l_d, so:

$$l_d = \left(L - L_A\right) c_d \Big/ \sum_{d'=1}^{M+1} c_{d'} \qquad (0.12)$$

The process of the genetic algorithm to optimize the setting of the ASA is as follows, and K is a maximum number of iterations:

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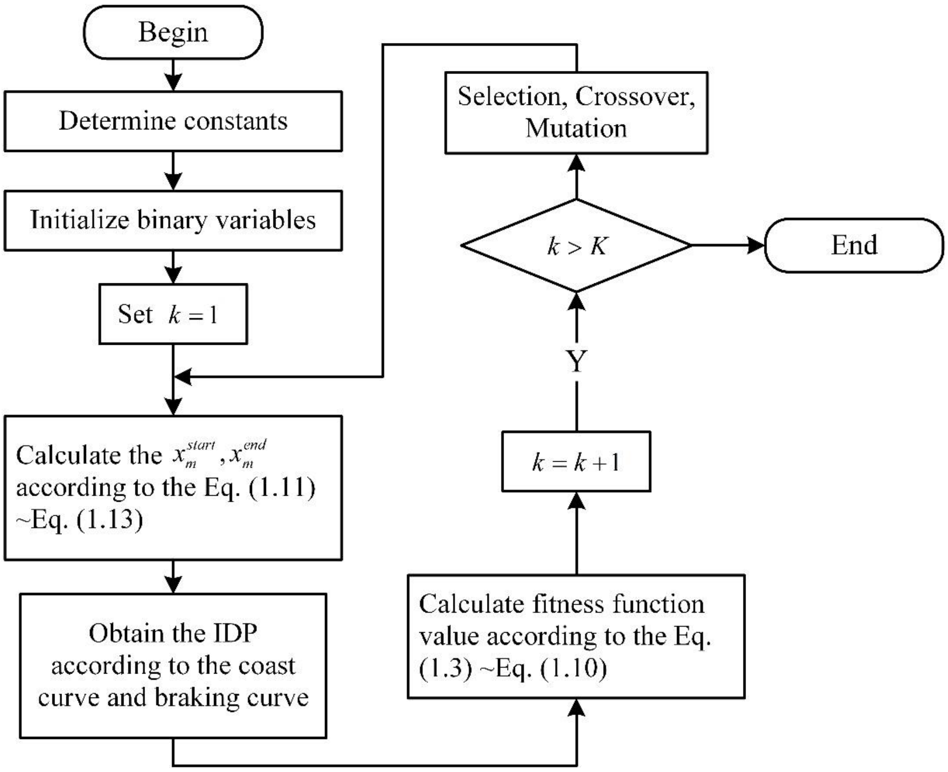

Fig. 4. The flow chart of the genetic algorithm to optimize the ASA

3. SIMULATION EVALUATION

A maglev line was constructed in order to validate the proposed model. The maximum limit speed was given as Table 2, and L=9000 m, L_A=4050 m. The braking curve and coast curve were obtained through the middle-speed maglev train which was under development by CRRC.

Table 2. The maximum limit speed

Speed limit section	speed
0~541.5	80
541.5~1431.2	200
1431.2~1534.7	80
1534.7~1849.7	180
1849.7~2107.5	100
2107.5~2660.8	200
2660.8~3263.8	120
3263.8~3906.2	150
3906.2~4556.9	200
4556.9~5329.6	180
5329.6~5621.9	100
5621.9~6058.3	200
6058.3~7018.6	80
7018.6~7190.5	200
7190.5~8328.4	100
8328.4~9000.0	80

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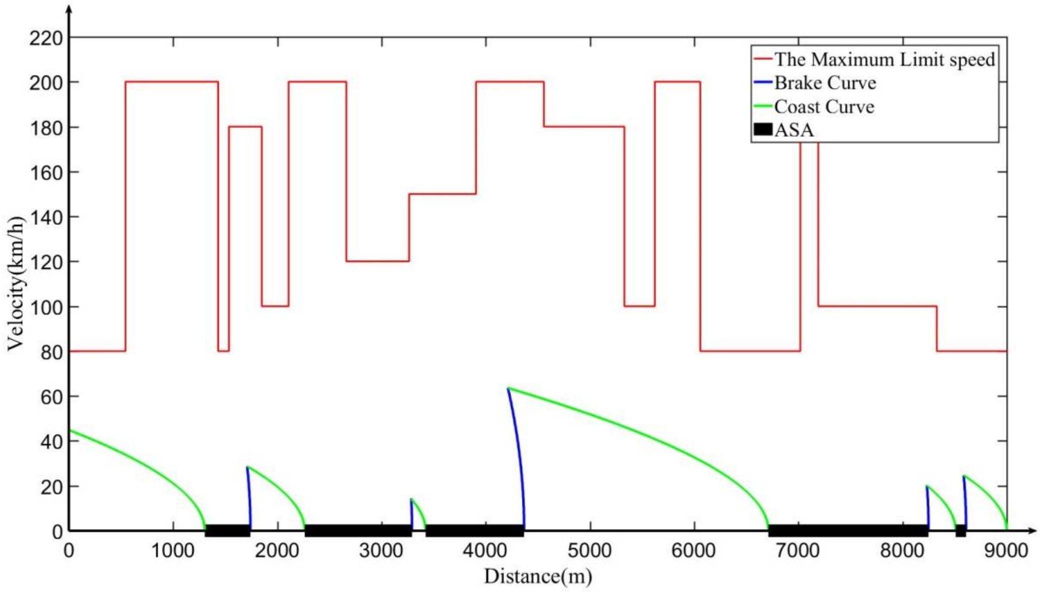

Fig. 5. The setting situation of the ASA before optimize

Fig. 5 shows the setting situation of the ASA which was produced by random initialization process. The number of the ASA is five, and maximum length of the ASA is 1536.9 m. The maximum length of the IA is 2344.7 m, which leads to the available area of speed too smaller.

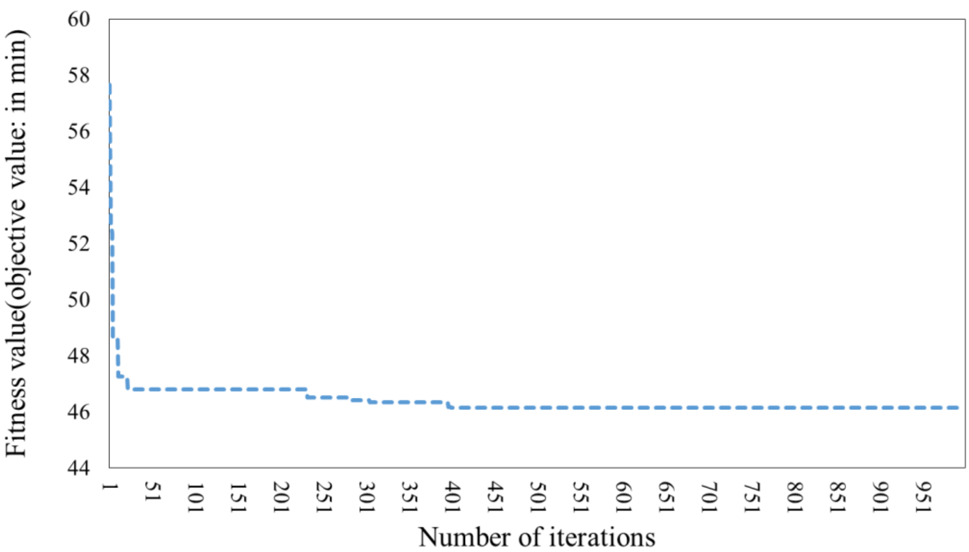

Fig. 6. The setting situation of the ASA after optimize

As illustrated in Fig.6, the iterative results of the genetic algorithm, and the minimum objective value decreases with increasing algebra until it is stationary. It is concluded that the genetic algorithm method can find better value for the model.

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The result of 1000th generation was shown in Fig. 7. Compared with Fig. 5, it is can be found that the number of the ASA is greatly increased, and maximum length of IA is reduced. The changes of the ASA will guarantee the maglev train operate in safety, even the speed of the train is lower. Therefore, the result shows that the proposed model for optimizing the setting of the ASA was practical.

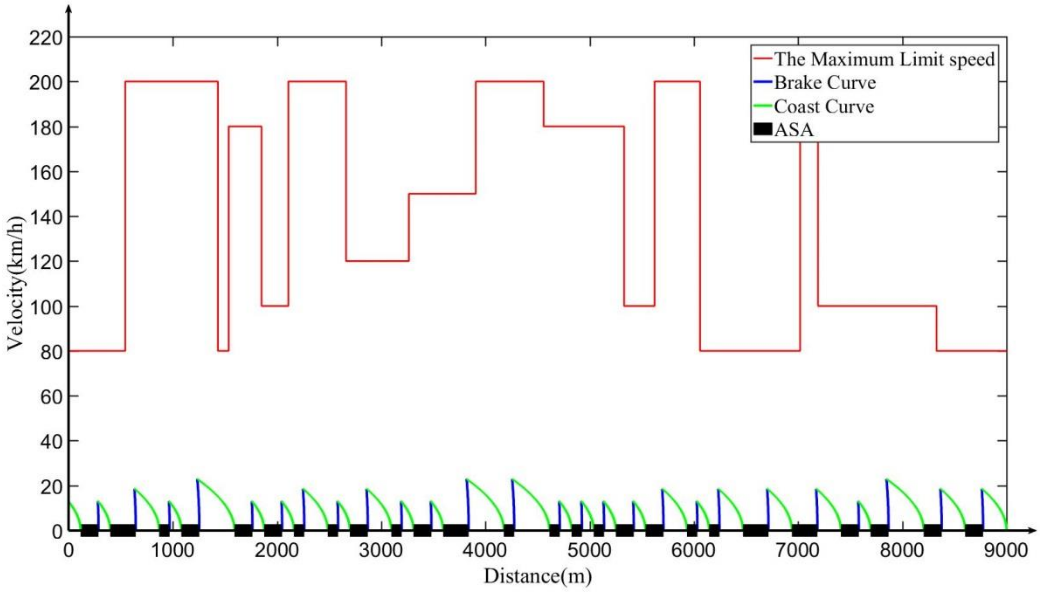

Fig.7. The iterative results of the genetic algorithm

5. CONCLUSION

A model to optimize the setting of the ASA on the middle-to-high speed maglev considering the operating robustness was built in this paper. This paper proposed two indexes to reflect the impact of station settings on train operations, which provides a method to optimize the ASA from qualitative optimization to quantitative optimization. The result of numerical examples shows that the proposed method can effectively improve the performances of the ASA.

In the future, we hope that the more line parameter is considered, which will make the model more practical. Furthermore, the impact of the ASA on multi-train also will be researched in the future.

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