Placement of the Assist Stop Areas in High-Speed Maglev System Considering Bidirectional Operation

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Abstract. The location of the assist stop area in high-speed maglev system is closely related to the operation and maintenance of high-speed maglev train, which is the basic condition for continuous train operation. In this paper, a high-speed maglev assist parking area location setting method considering two-way operation is established. The method calculates the positions of assist stop area in both directions, and optimises the spacing and quantity to obtain the optimal placement of assist stop areas with the minimum quantity.

1. Introduction
The high-speed maglev system is one of the development directions for future railway transportation. The operation and control system of high-speed maglev adopts the stepping control based on stopping points, so the location planning of the Assist Stop Area (ASA) has become an important subject in the area of railway operation and control [1]. In [2], the paper purposed an algorithm to determine the location of the APAs in unidirectional operation scenario. The algorithm includes the maglev kinetic model, as well as the effect of air resistance and gradient. In [3], the author applied the algorithms for unidirectional operation into the bidirectional maglev system, which was implemented by applying into two directions separately. The paper indicates the gradient in the maglev system should be considered. Another method is demonstrated in [4], which is based on the baseline operational speed curve. The method calculates the placement of the ASA using the multi-objective speed curve of the maglev train in unidirectional operation, which analysed that the setting of the ASA can vary under different operational speeds.

The operation of the high-speed maglev railway adapts the bidirectional operation mode. As the second line can operate in the reverse direction when a failure occurs on one of the bidirectional lines, the placement planning of the ASA in both directions can introduce a significant benefit to the robustness of the maglev system.

2. Control Mode and Characteristics of the High Speed-maglev System

2.1. Stepping Control at Stop Points
In high-speed maglev system, the stepping control method at stop points is shown in Figure 1. The operation and control system always maintain the train speed under the safety braking curve of the current ASA and above the safety coasting curve of the next ASA. The stepping control is implemented in the permissive speed range, which allows the train to operate simultaneously. [4-7]
2.2. Characteristics of the Maglev Train
The parameters of the train characteristics include the traction acceleration rate, sliding braking deceleration rate and eddy current braking deceleration rate. In this paper, the traction acceleration is shown in Table 1, Table 2 is the sliding braking acceleration rate, and the eddy current braking acceleration is summarised in Table 3. [3] [4]

| Table 1. Traction Acceleration Rate |
|------------------------------------|
| Operation Speed (km/h) | 0-100 | 100-200 | 200-300 | 300-400 | 400-500 |
| Acceleration Rate (m/s²) | 0.9 | 0.9 | 0.7 | 0.5 | 0.2 |

| Table 2. Sliding Braking Deceleration Rate |
|------------------------------------------|
| Operation Speed (km/h) | 0-100 | 100-200 | 200-300 | 300-400 | 400-500 |
| Deceleration Rate (m/s²) | -0.04 | -0.09 | -0.18 | -0.3 | -0.4 |

| Table 3. Eddy Current Braking Deceleration Rate |
|-----------------------------------------------|
| Operation Speed (km/h) | 0-10 | 10-100 | 100-200 | 200-300 | 300-400 | 400-500 |
| Deceleration Rate (m/s²) | -1.0 | -0.11 | -0.75 | -1.08 | -1.28 | -1.44 |

3. Method of Setting the ASA
3.1. ASA Setting Method in the Unidirectional Scenario
Multiple ASAs are required to install between the two stations. The safety braking curve can be calculated based on the starting position of the ASA according to the sliding braking deceleration rate.
The ending point of the ASA can be used to calculate the safety braking curve based on the eddy current braking deceleration rate [8-10]. The operational speed curve between two stations can also be calculated by traction acceleration rate and the eddy current braking deceleration rate.

To reduce the construction cost of the high-speed maglev system, the number of ASAs between two stations shall be reduced to the minimum. In this case, the safety braking curve of the current ASA, the safety coasting curve of the next ASA and the operation speed curve of the train should intersect at one point [11-15], which eliminate the other influencing factors such as the wireless communication time during the stepping control process. The flow chart for deriving the location of ASA in unidirectional mode is shown in Figure 2. [2-4]

![Flowchart](image)

**Figure 2.** Method of setting the ASA in unidirectional scenario

### 3.2. ASA Setting Method in the Bidirectional Scenario

The flow chart for setting the ASA considering bidirectional operation is shown in Figure 3. The detailed steps are:

1. **Step 1:** Based on the two operational directions, calculate the location and quantity of the ASAs in each operational direction.
2. **Step 2:** Starting from the first ASA in one direction, search the location of other ASA onward.
Step 3: Check if any ASA from the opposite direction is passed when searching the ASA No. \(i+1\) from the ASA No. \(i\), if an ASA is passed, then calculate the spacing \(s\) between No.\(i\) ASA in two directions and execute Step 4. If not, perform Step 9.

Step 4: According to the calculation results of the ASA in two directions, we can obtain the number of ASAs between the No.\(i\) ASA in both directions, let it be \(n\).

Step 5: Calculate the average distance between the No.\(i\) ASAs in both directions, which can be derived by:

\[
\overline{s} = \frac{s}{n}
\]  

(1)

Where \(\overline{s}\) is the average distance, \(s\) is the distance between the No.\(i\) ASAs in both directions, \(n\) is the number of the ASA within the range.

Step 6: Determine whether the average spacing is less than the spacing between the No.\(i\) ASA and the No.\(i+1\) ASA; If the condition is satisfied, then the number of the ASAs can be further reduced. Then set \(n = n - 1\) and return to Step 5. If the condition is not satisfied, execute Step 7.

Step 7: Determine if the calculation is executed for the first time, and if not, perform Step 10; If so, it means that the spacing between the No.\(i\) ASA in both directions is too large to meet the requirement of stepping control, then execute Step 8.

Step 8: Determine whether the No.\(i\) ASA in the opposite direction has been encountered. If so, then the search is completed and execute Step 10. If not, then continue the search and return to Step 2.

Step 9: Output the location of the No.\(i\)-1 ASA and the total number of ASA.

Step 10: Output the average spacing and number of the No.\(i\) ASAs between two stations calculated in the latest iteration.

Step 11: Determine whether the No.\(i\) ASA is within the set of ASAs calculated in this direction. If so, it means that all the placement of ASAs have been calculated and execute Step 12. If not, return to step 2 to calculate the location of the next ASA.

Step 12: Select the optimal result of all the possible ASA placement solutions. First to ensure the minimum number of ASAs, and then to ensure the minimum ASA spacing.
Separately calculate the location of ASAs in both directions

Start searching the No. i ASA in one direction

If any ASA in opposite direction is encountered

YES

Calculate the distance between No. i ASA from both directions

Determine the number of ASAs between No. i ASA from both directions

Calculate the average ASA spacing

Output the quantity and the minimum spacing between No. i ASA from both directions

Obtain all the locations of ASAs between two stations

If the No. i ASA is within the set of ASAs between two stations

YES

Output all the possible solution with the minimum number of ASA

NO

i=i+1

If the No. i ASA from the opposite direction is encountered

YES

If this is the first iteration

NO

n=n-1

Figure 3. Method of setting the ASA in bidirectional scenario
4. Calculation Result and Analysis

4.1. Result in Unidirectional and Bidirectional Scenario

In this paper, a 50km high-speed maglev line is used for calculation. When the train's commercial operation speed is 400km/h, the calculation result of the ASA placement considering unidirectional operation is shown in Figure 4. The calculation result of the ASA placement considering bidirectional operation is shown in Figure 5.

As shown in Figure 4, when the commercial operation speed is 400km/h and the calculation method for unidirectional scenario is applied, the number of ASA required in the 50km straight line is 4. The maximum spacing between two ASAs is 19.616km. If the track is configured to run in both directions, 8 ASAs are required and the maximum distance between the two ASAs is 18.846km.

As can be seen from Figure 5, after applying the calculation method for the bidirectional scenario, only 6 ASAs are required for bidirectional operation in the same 50km test line. The maximum ASA spacing is 9.587km. The number of ASAs in this scenario is 25% less than that of the unidirectional scenario. The maximum spacing between the two ASAs is reduced by 49.13%. This proves that the establishment of auxiliary parking area setting method considering two-way operation in this paper can effectively reduce the number of auxiliary parking areas, reduce the maximum spacing between auxiliary parking areas, and better meet the requirements of high-speed maglev operation control system.

4.2. Result in Different Commercial Operation Speed

By applying the calculation method in the same 50km test line with the commercial operation speed of 200km/h, the ASA calculation result in the unidirectional scenario is demonstrated in Figure 6. The calculation result in the bidirectional scenario is shown in Figure 7.
As can be seen from Figure 6, when the commercial operation speed is 200km/h and unidirectional method is applied, 5 ASAs should be deployed in one direction the 50km test line, which is increased by 1 compared with the result at 400km/h. This indicates that the number of ASAs will decrease with the increase in the commercial operation speed.

In Figure 7, the calculation result in the 200km/h bidirectional scenario is basically the same as the 400km/h system. It indicates that when considering the bidirectional operation, the number of ASA will not decrease with the increase of commercial operation speed.

This is because the high-speed maglev train adopts the stepping control method. The method for setting the ASAs in the bidirectional scenario is to reuse the ASA in a reasonable approach, which reduces the ASA number. If the commercial operation speed is too high, the calculation results obtained by considering unidirectional operation is reduced; however, the spacing between the two ASAs is too large to apply the ASA reuse. Therefore, it can be concluded that on a straight line of a certain length, when considering the bidirectional operation, the position and number of the ASAs are the same in a certain range of the commercial operation speed.

4.3. Result in Different Line Length

By analyzing a 60km high-speed maglev line with the commercial operation speed of 200km/h and 400km/h, the ASA calculation result is shown in Figure 8 and 9.
As can be seen from Figure 8 and Figure 9, after extending the test line to 60km, the number of ASAs required for 200km/h bidirectional operation is 8; while in 400km/h scenario, the ASA number is increased to 7. It indicates that with the increase of the commercial running speed of the train, the ASA can be reused more efficiently in the bidirectional scenario when the length of the line is extended.

5. Conclusion
Through calculation and analysis, the following conclusions are obtained:

1) In this paper, the ASA placement method considering bidirectional operation can effectively reduce the number of the ASAs, which reduces the maximum ASA spacing and meet the requirements of high-speed maglev operation more efficiently.

2) In a straight line of a certain length, when considering the bidirectional operation, the position and number of the ASAs are the same in a certain speed range of commercial operation speed.

3) With the increase of the commercial operation speed of the high-speed maglev trains, the ASAs can be reused more efficiently when a longer line length is deployed.

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7. References
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