Study of Optimal Design Speed of High-speed Maglev Project

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ABSTRACT: The optimal design speed of transportation project relates not only to the national integrated transportation system structure, but also to the energy consumption structure of national economy and the traveling quality of passengers. Starting from the analysis to technical and economical characteristics of the Maglev-system, this paper tries to find the optimal design speed of high-speed maglev transportation system in different aspects such as the speed structure of integrated transportation system and the project benefit. As a result, it gives reference to the planning of high-speed maglev transportation project.

KEYWORDS: High-speed maglev transportation system; Optimal design speed

1 INTRODUCTION

1.1 Research significance of optimal design speed of high-speed maglev transportation system

The determination of the design speed is a strategic decision-making for a transportation model. It relates to the compatibility with social economic development. The design speed of a transportation model has remarkable influence on its construction and operation cost, the ability of its competition in transportation system, then its survivability further.

The design speed of high-speed transportation system is a basic precondition for its line-planning, developing and manufacturing of vehicles and other equipments, forecast of the market demand, the assessment of economical and social benefit. it is the most important parameter to develop a high-speed transportation system.

China has constructed a high-speed maglev train demonstrating operation line in Shanghai, and will research the technical feasibility and economical rationality of a new line from Shanghai to Hangzhou. The corresponding equipments of maglev system will be developed and manufactured domestically. It is urgent to study the optimal design speed of high-speed maglev system, which adapts to the social and economical development for a long period in China.

1.2 Technical definition of optimal design speed of high-speed maglev transportation system

1) The design speed of infrastructure
The maximum operating speed of maglev train in the near and far future is the basic parameter to design the alignment and infrastructure such as bridges and tunnels. It is called the design speed of infrastructure.

2) The design speed of mobile equipments
The maximum operating speed the train and related equipment would achieve, which could ensure the safety and comfort, is the design speed of mobile equipments. It is a basic parameter for the designing and manufacturing of all mobile equipments and corresponding sub-system. It may be raised step by step along with the market demand and the technical development. Therefore, the optimal design speed of mobile equipment of a project should be considered according to the conditions in the near and far

future.

3) The commercial service speed

The commercial service speed refers to actual operating speed of the train under synthetic consideration of the market demand and economic benefit of the project.

It can be determined according to many factors such as the function of a project in the whole transportation system, the competitive ability, the operating cost, the ticket price, the paying ability and the payment wish of passenger and so on.

To adapt the market demand and obtain the best economic benefit, including national economic benefit and social benefit, is the principle to determinate the commercial service speed. Along with the development of economy and society, the best commercial service speed will therefore change. So in different period there is different optimal commercial service speed.

1.3 Influence factor of optimal design speed of high-speed maglev transportation project

1) The optimal design speed of infrastructure will be affected by the natural conditions;

2) The optimal commercial service speed will be affected by the social and economic environment;

3) The optimal design speed of mobile equipments will be affected by the related industry technical level.

1.4 Research points of optimal design speed of high-speed maglev transportation system

The following points should be taken into account:

1) The technologically suitable speed range of high-speed maglev system;

2) The best speed to improve the speed structure of integrated transportation system;

3) The requirement on travel speed of passenger;

4) The influence to the optimal design speed for a certain project situation, such as the line length or travel distance, the local economic development level and the natural conditions.

2 THE OPTIMAL DESIGN SPEED OF HIGH-SPEED MAGLEV TRANSPORTATION SYSTEM SUIT TO ITS OWN TECHNICAL CHARACTERISTIC

Let's consider the present relative mature Transrapid system. The linear synchronous generators cannot provide sufficient power to operate the train at 100 km/h or below due to its own technical characteristic. For the speed range of 100~200km/h, the maglev train cannot provide economical operation because of the high resistance of linear motor, according to the relationship between moving resistance and operating speed of maglev-train's ①, which is shown in figure 1. Thus, the suitable commercial service speed of high-speed maglev train should be higher than 200 km/h.

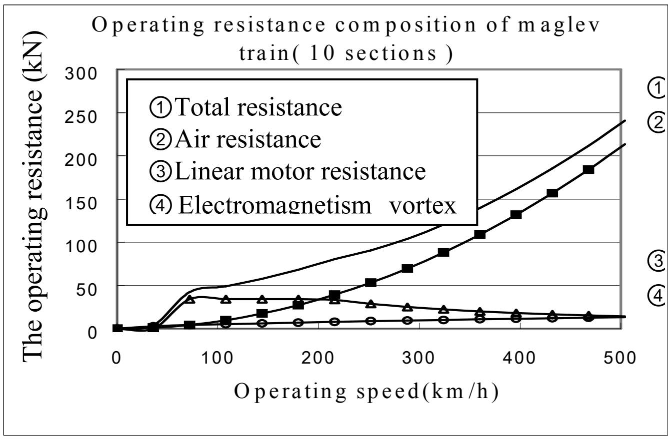

Figure 1: Relationship between movement resistances and operating speed of high-speed maglev train

Theoretically the air resistance is in proportion to the square of speed. The air resistance of the maglev train travels at 500 km/h is nearly three times as that at 300 km/h. For the speed higher than 500 km/h, the system will become not efficiency due to very high air resistance, thus will be supposed to be operated in thinner air environment or like the airplane flying in superior atmosphere with low air density. According to the technical characteristic ① of the TR07, the maximum speed of train with 10 sections can only achieve 475 km/h (see Figure 2). By less sections or higher voltage of the propulsion system the maximum speed could achieve or surpass 500 km/h.

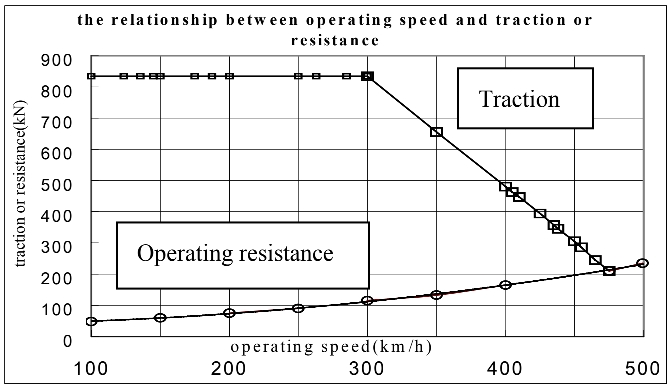

Figure 2: The traction and operating resistance of TR07 train with 10 sections

Therefore, the maximum surface speed of high-speed maglev train should be controlled in the range of 500~550 km/h.

3 RESEARCHES ON THE OPTIMAL DESIGN SPEED INSPECT OF THE SPEED STRUCTURE OF THE INTEGRATED TRANSPORTATION SYSTEM

From the viewpoint of technical characteristics of high-speed maglev system the suitable operating speed is in the range of 300~550 km/h. It could thus be used in intercity passenger transport. In order to get the suitable commercial service speed of high-speed maglev train, we discuss here from the speed structure of transportation system in China.

3.1 The existing speed structure of intercity transportation system in China

The existing intercity passenger transport system in China considered here includes the conventional railway, roads in different class and the civil aviation. The water corridor is not here because its speed is much lower than other transportation's, and this transport is being disused by passenger due to enhanced value of time along with the development of economy.

The following Figure shows the average operating speed of main intercity passenger transportations at present in China.

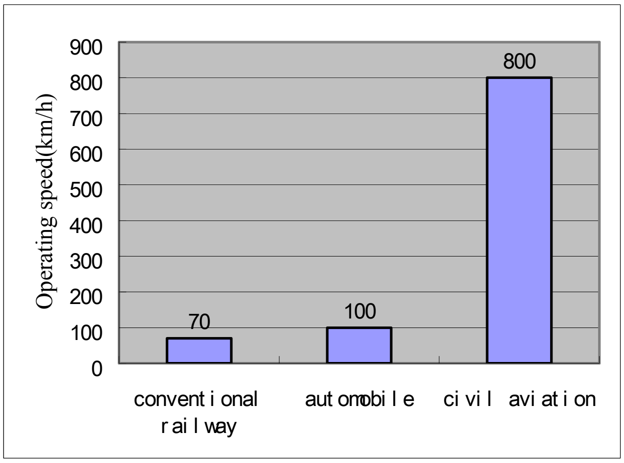

Figure 3: The average operating speed of main intercity passenger transportation at present in China

3.1 The speed structure of the intercity passenger transportation system with high-speed maglev train

There is a speed blank of about 700 km/h in the present speed structure while the speed of railway train or automobile is of 70~100 km/h and the civil aviation of 800 km/h approximately. The operating speed of high-speed maglev train can achieve 400 km/h, thus the speed structure of the whole intercity transportation system will be changed (see Figure 4) when it is introduced.

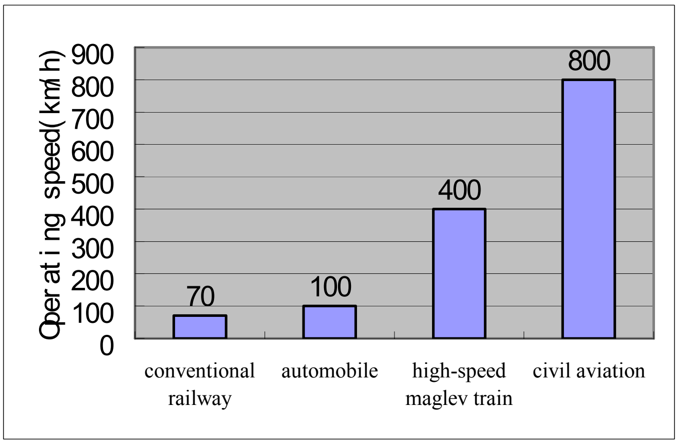

Figure 4: Speed structure of passenger transportation system with maglev train

According to Figure 4, there will be a reasonable speed structure of passenger transportation system when the high-speed maglev train is introduced in. The low (100 km/h), middle (400 km/h) and high (800 km/h) operating speed coexist in the system.

If we construct new high-speed railway or rebuild the existing line and introduce tilting technology, we can enhance the railway train speed approximately up to 250 km/h. As a result, the speed structure of the whole passenger transport will be more reasonable. (see Figure 5)

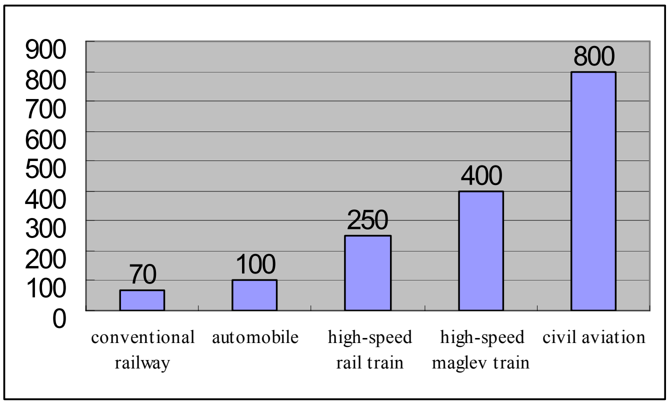

Figure 5: Speed structure with high-speed maglev train and high-speed rail train

According to the analysis above, the operating speed of high-speed maglev train should be about 400 km/h and the corresponding highest operating speed could take 450 km/h. Besides, the demand of travel speed is getting higher with the development of social economy. So the design of fixed facility should meet the need of trains with a highest running speed of 500 km/h.

4 RESEARCHES ON OPTIMAL DESIGN SPEED OF PROJECT INSPECT OF MARKET BENEFIT

The traffic volume, project investment and operating cost are very important basic data during the planning and decision-making on high-speed maglev transportation. They have significant influence on the economic benefit of a maglev project. Analyzing quantitatively the influences of design speed on these basic data is very important for quantificational and reasonable decision-making.

4.1 Influence of design speed on project investment

The main influences of design speed on construction cost of civil engineering are as follows:

1) The higher the speed is, the larger the curve radius required for the sake of comfort and safety will be. As a result, both the adaptability of line with topography and the capability to bypass the obstacle will be lower. Accordingly, it will increase the cost of building-dismantling and infrastructure;
2) The higher the speed is, the more the aerodynamic influence created by the train moving will be. To assure the safety of the train operating, it needs larger space between the two parallel lines. Accordingly, the investment will increase with more land consumption;
3) The higher the speed is, the stronger the dynamic effect created by the train moving will be. Thus, higher strength, rigidity and fatigue endurance of the infrastructure will be required. Accordingly, It leads to larger dimensions of the structure, more steel consumption and larger areas of tunnel cross-section. Then the constructing cost will be increased.
   In addition, the higher the operating speed is, the higher the technical requirements on all equipments of the train will be. Sequentially, the manufacture cost and purchasing fee of the train will be increased.

4.2 Influence of design speed on operating cost

1) The cost of energy-consumption increases when the speed increased;
2) The maintenance cost of trains increases when speed increased;
3) The maintenance cost of infrastructures increases when the speed increased;
4) The expense on passenger transportation increases when the speed decreased.

4.3 Influence of design speed on operating revenue

Higher operating speed will shorten the travel time and then attract more passengers by constant fare, or we can raise the fare without customer losing, because the payment will of passenger increases. Then the operating revenue will increase.

4.4 Influence of the maglev project's design speed on economic benefit

Economic benefit of a project is the sum of annual cash flows.

The annual cash flow can be calculated from the operating revenue minus the annual investment and operating expense. The above data are discounted into present value at the time of starting year.

The economic benefit of a project is as follows:

$$OBJ = MAX(NPV) = \sum_{i=m+1}^{n+m} R_i(V, VOT, i,) \bullet (1+R_D)^{-(i-1)} - \sum_{i=1}^{m} A_i(V, R_G, i) \bullet (1+R_D)^{-(i-1)} - \sum_{i=m+1}^{m+n} E_i(V, i) \bullet (1+R_D)^{-(i-1)} + A_s(V, R_G) \bullet (1+R_D)^{-(n+m)}$$

where,

NPV is net present value;

$R_i(V,VOT,i)$ is operating revenue in operation year(i), which is relevant to the design speed(V), passenger's value of time(VOT) and the operation year(i);

$A_i(V,R_G,i)$ is the investment in the year(i), which is relevant to the design speed(V), natural condition factor (R_G) and the year of the project development;

$E_i(V,,i)$ is the operation expense in the year(i), which is relevant to the design speed (V) and annual amount of passenger transported;

$A_s(V,R_G)$ is the remaining value of the fixed assets at the end of the calculating period of the project. Its amount is relevant to the original value, accordingly it also relevant to the designing speed (V) and the natural condition factor (R_G);

R_D is the discount rate.

4.5 Computation cases

In order to get the biggest net present value using the theory and method described above, we can get some optimized result in different situations.

The sample project is located in plain topography, with a length of 1300 km. The average value of time of passenger ranges from 22 to 33 RMB per hour during the calculating period of the project. We get the optimal design speed as 503 km/h.

Based on the basic data of this sample project, the authors analyze the influences of some factors on optimal design speed. Those are the topographic conditions, the length of the line and regional economic development level which is described as the average VOT of passengers.

Results can be seen in table 1 to table 3.

Table 1: The influence of topographic conditions on optimal design speed

Topographic condition	Plain region	Hill region	Middling mountainous area	Mountainous area
The optimal design speed (km/h)	503	468	429	386

Table 2: The influence of the length of line on optimal design speed

The length of line(km)	1300	1100	900	700	500	300	100
The optimal travel speed (km/h)	503	502	499	496	490	476	411

Table 3: The influence of average VOT of passenger on optimal design speed

The coefficient of average VOT of passenger	1.00	0.95	0.90	0.85	0.80	0.75
The optimal design speed (km/h)	503	496	490	484	478	471
The coefficient of average VOT of passenger	0.70	0.65	0.60	0.55	0.50	
The optimal design speed (km/h)	464	457	449	441	433	

In the table 3, the coefficient of average VOT of passenger is the ratio between the average VOT of passengers where the project located and the corresponding value of the basic case.

5 CONCLUSION

For a certain maglev project, the design speed should be determined by considering many factors, which are the concrete transport system the project located, the economic development level, the length of the line, the natural conditions and so on.

REFERENCE

Ruediger Fuerst. Anwendungsnahe Dimensionierung und messtechnische Ueberpruefung von Langstator-Linearmotoren fuer Magnetschnellbahnen. Berlin: Dissertation 1993.