Research on Alignment Planning & Designing of High-speed Maglev Guideway

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ABSTRACT: The paper describes the research work on the design technology, fitting technique, error distribution and stator-pack arrangement technique of small-radius guideway as well as the influence of guideway settlement on long-wave errors. It also probes the technology and method of guideway measurement.

1 INTRODUCTION

The commercial operation of Shanghai Maglev Demonstration Line symbolizes the advent in the area of high-speed maglev transportation application. It is imperative to study the key technology and get it applied and popularized on a wider scope. Viewed from the guideway technology, the minimum radius applied on the main line of Shanghai Maglev Line is 1,300 m, but according to the Technical Specifications, the minimum turning radius of maglev vehicle is 350 m. From the angle of project implementation, the paper lays the emphasis on the fitting technology, error distribution, stator pack arrangement and their measuring techniques.

2 GUIDEWAY FITTING TECHNIQUE

2.1 Geometric Requirement of Guideway Line

The functional planes provide the action planes for levitation, guidance and braking of maglev train as well as the supporting planes for gliding and stopping. As to hybrid girder, these action planes are realized by functional modules.

Functional module is a steel structure welded with web plate, top plate, side guiding plate, lower flange plate, vertical stiffening plate and horizontal stiffening plate. The top plate serves as a gliding plane and the side plate as a guiding plane. The lower flange plate is used to fix the stator packs and the web plate provides a connecting plane for brackets. The module is fixed on the guideway girder by means of bracket. It receives the force transmitted by the maglev train and conveys the force to the guideway through the bracket. Three functional planes on both sides of guideway form the track of the maglev transportation system. At the curved section of the guideway, each of the planes at the module is varied with the line conditions according to set rules.

To ensure the safety and comfort of the maglev train at a high speed, the guideway structure, the design and manufacture of the guideway functional zone and the location of girders must satisfy the specified levitation gap, i.e. 8~12 mm between the levitation magnet and the guidance functional planes and between the guidance magnet l and the stator functional plane.

Geometric error of the functional plane has two aspects: one is the offset that can be directly measured, such as location deviation, the dislocation and the angle of torsion, the gap, the gauge and tong size, etc.; the other is the offset that can be calculated or analyzed from the measured data, such as the long-wave error, short-wave error, gradient change criterion (NGK), etc. The geometric deviation indexes of the functional planes are shown in Table 1 below.

Table 1: Geometric Deviation Indexes of Functional Planes

Functional plane		Stator pack plane SE			Side gliding plane SFE			Gliding plane GLE		
		X	Y	**Z**	X	**Y**	Z	X	Y	**Z**
Allowable position offset(mm)(absolute)		2.0	**2.0**	1.0	1/-5	**2.0**	10	16		
Allowable OFFSET(mm)	Inside			**0.4**		0.6				**0.2**
	Top			**0.6**		1.0				**0.6**
NGK(mm/m)	Inside			**1.5**		**2.0**				**3.0**
	Top			**0.75**		**1.0**				**1.5**
Gauge allowance(mm)						1.0				

In Table 1, as to the stator pack plane, the relative deviation in Z-direction and the absolute position deviations in X, Y, Z directions are the main considerations. As to the side guidance plane, the main consideration is the absolute deviation and the relative deviation in Y-direction and the gauge; as to gliding plane, it is the relative deviation in Z-direction.

In general, the stator pack plane and the gliding plane adopt curves fitted with short straight lines and the side gliding plane may use a plane fitted with plane surfaces or curved surfaces. Any fitting may produce an error. The fitting error is a design error (method error). The design must strictly abide by the stipulations in Table 1 and the magnitudes of errors must be controlled, i.e. the total of fitting error and the error reserved for installation shall not exceed the values shown in Table 1.

As to the straight line section, the errors listed in Table 1 are only the errors of machining, installation and the locating error on site. As to the curved section, due to the adoption of fitting technique, the errors, apart from the above-mentioned, should include the design error. In Table 1, the figures in bold type are the fitting errors that should be considered in the design.

The high-precision geometric requirements include the accumulative error of design, construction (machining, installation and positioning) etc. If the design fitting takes up too much of the error, the construction error must be stringent. On the contrary, if the design fitting error is small, the error reserved for construction is big and the construction is comparatively easy. However, reduction of design error will make the structure of components more complicated and may increase the difficulty in the construction. Therefore, reasonable allocation of errors in the design and construction phases is extremely important.

2.2 Analysis of Fitting Method

On the premise of satisfying system requirements, the fitting of curved section is realized in 3 levels, i.e. straight girder adopts curved flange, functional module uses broken lines to fit curves and linear stator packs on straight line arranged into straight line or broken line to fit a curve.

The method of straight-line fitting and curve fitting is as follows:

(1) Within the range of a functional module, use straight lines to fit the theoretical axis at center of bottom surface of stator packs and use planes to fit the theoretical torsion surface of the bottom surface of stator packs.

(2) Within the range of a functional module, use the straight lines to fit the center line of gliding rail plane and use planes to fit the theoretical torsion plane of gliding plane.

(3) Within the range of a functional module, use curves to fit the center line of gliding rail plane of functional module, use planes or cylindrical surfaces to fit the theoretical torsion plane of guidance rail plane.

The purpose of fitting is to reduce the machining difficulty of functional module, reduce the workload of machining so as to guarantee the project schedule and satisfy the project requirements.

3 ERROR PRODUCED BY FITTING

The total error consists of the design error, manufacture error and the installation error. If the design error is too big, there must be a high requirement on manufacture and installation errors. Therefore, a comprehensive consideration must be given to design, manufacture and installation errors so as to attain an optimum result.

In accordance with the system requirement, the error brought about by design fitting is shown on the 3 functional planes in different degrees.

On the stator pack plane where straight lines are used to fit a curve and the adjacent stator packs are arranged symmetrically, the design fitting error Offset = 0. The design error comes mainly from the allowable Y-direction deviation and the NGK in Z-direction. Offset = 1/2δ is adopted to distribute the error equally. The total allowable error in Y-direction is ± 2 mm. In places where there are vertical curves, the total deviation of NGK in Z-direction of stator packs is ± 1.5 mm/m inside the girder and ± 0.75 mm/m at the girder end.

On the side guidance plane, curves are employed to fit the curve. Fitting error may appear in Y-direction in the design. The allowable position deviation is ± 2 mm in Y-direction. The total allowable deviation of NGK inside the girder is ± 2 mm/m and ± 1 mm/m at the girder end.

On the gliding plane where straight lines are used to fit the curve and adjacent functional modules are arranged symmetrically, the design fitting error Offset = 0. The design error comes mainly from the NGK in Z-direction of the vertical curve. Total allowable deviation of NGK in Z-direction ± 3 mm/m inside the girder and ± 1.5 mm/m at the girder end.

4 FITTING ERROR ANALYSIS OF SMALL-RADIUS CURVE

4.1 Error of Stator Pack Plane

For equal distribution of error, stator packs are arranged according to ***half-rise of bow,*** they are arranged in a radial or linear way.

In straight-line arrangement, stator packs are placed along the axis of web plate of functional module. The bottom planes of stator packs of the same module are kept on the same plane, having the identical cant, gradient and azimuth.

In radial arrangement, it insures that the center of bottom face of each stator pack is located at the theoretical axis of stator packs. Stator packs are placed at the tangent direction along the theoretical axis, the cant being the theoretical cant of the center of the bottom faces of stator packs. Each stator pack has its own cant, gradient and azimuth. Stator packs within the range of a module are arranged as a polygonal line.

Table 2 shows the maximum positioning errors in various cases. It is shown on the 3,096 mm long functional module, the maximum error of the linear arrangement of is 1.5 mm and that when arranged radially is 0.17 mm, relatively a small error, but it is difficult for the stator pack to be positioned. If short stator packs (2,064 mm) are adopted, when arranged linearly, the maximum positioning error is 0.67 mm. However, it will cause much difficulty in machining and positioning, e.g. the difficulty in redundant positioning of brackets, etc.

Table 2: Positioning Errors of Different System Lengths

	Radius of Horizontal Curve (m)	Length of System(mm)	Rise of Bow(mm)	Half-rise of Bow(mm)
Radial Arrangement of 3,096 mm Module	400	1032	0.33	0.17
Linear Arrangement of 3,096 mm Module	400	3096	3.00	0.50
Linear Arrangement of 2,064 mm Module	400	2064	1.33	0.67

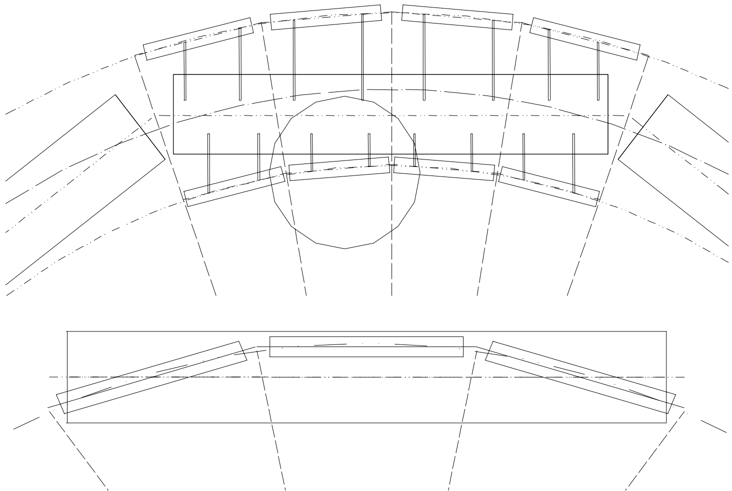

Fig. 1: Radial Arrangement of Modules and Stator Packs

At the places of vertical curve, the fitting will bring about NGK in the Z-direction. At the place of horizontal transitional curve, stator packs inside and outside will produce a deflection offset around the X-axis, see Table 3 for details.

4.2 Deviation of Guidance Rail Plane

"Fitting curve with curve" is adopted for the guidance rail plane. Table 3 shows the position deviation in Y-direction, NGK in Y-direction as well as the offset of deflation around Y-axis during fitting the radius of 400 m using radius of 490 m.

4.3 Deviation of Gliding Plane

"Fitting curve with straight line" is adopted for the gliding plane. NGK in Z-direction o gliding plane at the vertical curve and the offset of deflection of gliding plane around X-axis at the horizontal transition curve are shown in Table 3.

To sum up, the fitting errors in the designing of these function planes are shown in Table 3. The rest of the error will be dealt with by the process of machining, So in designing of the planes fitting errors should be minimized as far as possible so that much room can be left for the machining errors, thus making the machining easier and efficiency higher.

Table 3: Fitting Errors for Designing Sharp Radius Curves

Functional Plane	Fitting Error		Max. Value of Fitting Error	Percentage in Total Admissible Error	Remarks
Stator Plane	Y-direction position deviation (absolute)	Linear arrangement	1.4924 mm	74.60%	Fitting a curve with straight line
		Radial arrangement	0.3328 mm	16.60%	
	Z-direction NGK		0.172 mm	11.47%	At vertical curve
	Deviation of deflection around X-axis	Linear arrangement	0.09288 º	75%	At horizontal transition curve
		Radial arrangement	0.03096 º	25%	
Guidance Rail Plane	Y-direction position deviation (absolute)		0.2750	13.75%	Fitting a curve with straight line (Fitting R-400m using R-490 m)
	Y-direction NGK		0.62497	31.25%	
	Deviation of deflection around Y-axis		0.09588 º	50%	At horizontal transition curve
Gliding Plane	Z-direction NGK		0.172 mm	5.73%	Vertical curve
	Deviation of deflection around X-axis		0.09288 º	24.50%	Horizontal transition curve

5 TECHNOLOGY OF GUIDEWAY MEASUREMENT

5.1 Measurement of Guideway Settlement

In order to know the status of the guideway settlement during the construction and operation of the maglev line, it is necessary to arrange settlement observatory points at various foundation slabs of the guideway girders and piers and carry out regular observations. And then the settlement rate can be calculated, a curve of settlement plotted and a law governing the settlement found based on the analysis of the settlement trend and the status of settlement change. It is further possible to provide basic data for the construction of maglev guideway, the operation of maglev trains and the optimization of guideway designing.

Selection of Observation Interval:

(1) During the Construction:

After the completion of a foundation slab, the elevation of the settlement point on the slab is measured as the elevation of the initial measurement. After the completion of the placement of a pier but before the erection of a guideway girder, the elevation of the settlement point on the foundation slab and on the pier is measured at the same time and the elevation is transferred from the foundation slab to the pier as the initial observation of the settlement point of the pier for settlement calculation. Before the erection of the guideway girders, the second observation will be carried out at the settlement observation point on the piers and the settlement be calculated. After the erection of the girders but before the fine adjustment of the girders, a settlement observation will be carried out at the settlement observation point on a pier once a week and the settlement be calculated. The number of observations to be carried out is fixed at four,, however appropriate adjustment can be made as to the observation interval, depending on the settlement rate. After the fine adjustment of the guideway girders of the whole maglev line is accomplished, a settlement observation will be carried out on the settlement observation points of all the piers along the whole maglev line and the settlement calculated. Before the operation of the train, a settlement observation will be carried out at the settlement observation points along the whole line and settlement calculated.

(2) During the Operation after the Completion of the Project:

An observation is performed either every 3 months or every half a year. Such frequency may be adjusted, dependent upon the settlement rate.

5.2 Measurement of the Space Curve

After the completion of the fine adjustment of the guideway girders along the whole maglev line, it is necessary to carry out at regular intervals the observations of the actual space curve of the guideway girders, watch the law governing the change of the curve and analyze the cause for the change so as to provide basic data for the future design. The first measurement should take place immediately after the acceptance of project. It can be regarded that the position of the guideway girders having been fine-adjusted complies with the designing requirements and can be used as the initial value of observation, i.e. zero observed value. Afterwards, an observation will be carried out every half a year and the observed value will be compared with the last observed value, finding out the difference and the law governing the change, i.e. the difference between the actual space curve and the theoretical space curve.

5.3 Distribution of Measurement Points

Observation points are deployed at both ends of each guideway girder. Every girder is provided with 4 points in the form of embedded holes, i.e. 2 screw holes are drilled on either side of the steel plate in advance and measurement flags, which are stainless steel screw nuts in construction, may be placed at the preformed screw holes on the erecting plate of the guideway girder about 5 mm above the level of the erecting plate.

6 CONCLUSION

It can be seen from the above analysis that for the sharp-radius curve having a radius of 400 m with a relatively low passing speed, the maximum fitting error of the position deviation of stator plane in Y-direction is 1.5 mm. So if the machining and mounting errors can be controlled to the range of 0.5 mm, then it is still possible to ensure that the remaining errors are kept to the controllable range by using function modules 3096 mm in length, by arranging these stator packs in a straight line and by adopting the same machining and mounting means.

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