Alignment measurement and control of maglev track

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ABSTRACT: It describes the special features of maglev track, geometric and alignment requirements of maglev track and the deviation concept of the geometric requirements. It emphasizes the importance of alignment measurement during the operation of the line, which is centered on 3 measurement means (optical, mechanical and electrical), data analysis methods and their characteristics as well as the process for adjusting the alignment of the maglev track.

1 FORWORD

The guideway of shanghai maglev has been operated and maintained for more than four years already. as we know, the requirement of guideway and it's maintenance mode in commercial operating phase are quite different from those in the system developing phase. Based on our experience in traditional construction maintains, according to the technical requirements of German Maglev System TR08, we explored and exercised a series of measurement and adjustment methods. The application of these methods has helped us realize the monitoring and control of the guideway, and thereby can fulfil the fundamental conditions for the operation of Maglev train. On the other hand, we also find some limitations of these methods during the application of them, which will definitely help us on our way to find new measuring methods.

2 CHARACTERISTICS OF THE MAGLEV GUIDEWAY

As one kind of transportation construction facility, the Maglev Guideway features similar construction characteristics like the traditional railway. Besides, as one kind of electronic facility, its special features is also required to match the overall operational control requirement. These characteristics are of great importance for us to deal with the system and serve as a uniform foundation for the solution.

From the point of view of construction characteristics, geology will inevitably exert an influence on buildings, which has to be taken into careful consideration ever since construction phase up to operation phase. The geological conditions produce a direct impact on construction and maintenance cost of the guideway. Shanghai Maglev Line, located in the area of the alluvial plain of the lower reaches of Yangtze River, where has young gravel stratum and soft clay, in order to avoid the potential risk of settlement in soft clay, full consideration has been taken into the struction during the sub-struction design properly, so as to ensure the relative stability of the guideway in its life cycle. Besides, the alignment is also restricted by the geological conditions, as it is always a major principle for alignment optimization to make a detour for unfavourable geological region. Besides, the guideway structure is also restricted by construction technique and engineering material. With the development of science and technology, the construction technique and engineering material are changing with each passing day. In order to perfect the maglev guideway project, German experts carried out a great number of experiments and research on construction technique and engineering material. In the early phase they proposed several feasible plans. After comparing the steel structure girder and concrete girder, Shanghai Maglev Line selected the latter one on the basis of consideration for construction technique and material cost, of course, this selection make a strong impact on the maintenance plan and maintenance cost in the operation phase.

Compared with the line of traditional rail tranportation line, the guideway of the maglev system features the following characteristics,

– *Vehicles run on the Transrapid Maglev Line with high speed (in general 400 to 500 Km/h).*

– *Although vehicles do not touch the guideway directly when running time, the levitation gap and guidance gap is the essential relationship between vehicle and guideway.*
– *One kind of complex sinusoid solutions has been used as transition curve to improve the passenger comfort from beeline to circular curve in maglev alignment.*
– *Due to its 'fat' structure, it is very difficult to mount or adjust guideway girder. In Shanghai Maglev Line, we used 700-ton crane to lift and mount the 25-meter girder, most of which is more than185-ton weight. We also used strong jack for adjustment, which will be mentioned later.*
– *Guideway equipments mounted on the guideway (e.g. stator pack, propulsion winding, location flag, power rail, rotor location antenna, and earthing system) are generally electrical components, and have installation tolerance requirement with girder.*

Maglev vehicles are propelled through the mobile magnetic field produced by the stator windings mounted on the guideway, which also means that the propulsion power is get from the guideway. The high starting and decelerating acceleration and the great changes of live load on the guideway have put high demands on the stability of the guideway.

All of these characteristics show a higher construction and maintenance precision of the guideway than that of the traditional rail transportation line. We learned about it in the period of construction and operation in Shanghai Maglev Line.

3 DEFINITION OF GEOMETRICAL DEFLECTION ON THE MAGLEV GUIDEWAY

In order to fulfil the requirements of the train operation kinetics, maglev transrapid system has higher requirements on the alignment than any other rail transportation means. With mathematical and physical inferences and calculations, and on the basis of several years of experiment and research of German experts on TVE maglev line, a viable measuring standard have been fundamentally set up, including long wave and short wave departure, installation tolerance in each direction of each component. These geometrical requirements are fitting with each subsystem in the maglev transrapid system, including guideway, vehicle and operation control system. Some common limit values of short wave departure are listed as Table1.

Table 1: Common limit values of short wave departure

Setting	Within beam		Within function unit or stator pack	
	OFFSET	NGK	OFFSET	NGK
Levitation plain	0.6mm	0.75	0.4mm	1.5
Guidance plane	1.0mm	1.0	0.6mm	2.0
Slide plane	0.6mm	1.5	0.2mm	3.0

Long wave defection is mainly used to reflect the global defection of a single component or one section of guideway from the point of view of operation stability of a train or passenger comfort. In manufacture of the girder, the long wave defection is used for individual evaluation of single girder. It is the linear difference between the design and manufacture measurement data within one girder. While the girders have been mounted on the track, and take the precise adjustment of the girders, connect all of individual girder, the long wave defection is used for the evaluation of the alignment of a guideway section nice or not. It is of very importance for smooth operation of maglev trains.

Short wave defection is mainly used to reflect the relation between components and to thereby ensure the passable safety of maglev trains on the track. It is described with several aspects, such as "Offset" within the function unit and stator pack, one named "NGK" describe the inflexion between each adjacent girder /function unit/stator pack, it's the sign of transition smoothly or not, it's come from maglev train operation demand.

4 IMPORTANCE OF GUIDEWAY MEASUREMENT FOR COMMERCIAL LINE

It is necessary to keep the action of monitor and measurement on guideway during operation. Due to the foresaid intrinsic attributes of the civil engineering, guideway conditions are usually affected by construction foundation and operation environment. Therefore, we can not guarantee the guideway to remain in ideal condition all the time. For the goal of keeping in better conditions, what we can do is take adjustment or replacement to the related component units after measurement and evaluation, we can get the quantitative indicators of the guideway states by the way of comprehensive analysis. These are actually what we are doing in Shanghai maglev line now. We have taken three rounds of measurement in these three operating years. At the beginning, we found the vehicle swaying more obvious than before in some track section, and detected the scratching of vehicle's slide on the guideway also. We made the Z-direction measurement on related sections and adjusted the vertical alignment. As a result, we im-

proved the relation between the vehicle and the guideway partially. In the recent round of measurement, we made a comprehensive measurement and adjustment in each direction of partial sections, and get better result, vehicle operation on guideway was improved. However, it is still very hard for us to maintain the stability of the guideway in current operation. Similar situation occurs in the traditional railway maintain institutes, one of their major work is rail adjustment for improve the alignment. Among maintenance works in both maglev transrapid system and rail system, measurement is of fairly important.

Besides, the equipments mounted on the maglev guideway are base units of the maglev guideway. Each installation deviation of functional components and stator windings on the function component will impair the performance of the guideway. Other components, including power rail, location flag, cable and earthing system are located by relevant geometrical relation to the guideway, so part of their maintenance work should be based on it. These installation deviations have to be confirmed by relevant measuring methods before adjustment and maintenance work.

We have a special track in the vehicle maintenance hall of the maintenance area, whose size information will be quite useful for the maintenance technicians to calibrate the levitation face of maglev train and thereby to guarantee good geometrical condition of train's structure, as well as the rationality of geometrical function of train's levitation and guidance in operation. In order to do these, scheduled regular measurement should be carried out to get the size of this referenced track for the adjustment of the install location of levitation and guidance modules. LMS (laser monitoring system) was installed on the track sections where vehicles must run through, so as to measure the geometrical conditions of function surface of vehicles. If these geometrical facets are not under idealized conditions, we can put it right by the way of adjustment with the referenced track and its geometrical data.

Due to the above mentioned reasons, measurement should be taken as the scheduled maintenance work for guideway check. We should take measuring maintenance work before the obvious problems occur, otherwise it will reduce the performance of the system to some extent and even trigger safety problems. Therefore, we say that measurement is an important way for preventative maintenance work and is especially important for the commercial line.

5 MAIN METHODS AND APPLICABILITY OF MEASUREMENT OF MAGLEV GUIDEWAY

A variety of measurement methods can be roughly divided from an applicability point of view into optical method, mechanical method and electrical method.

Of all these methods, optical measurement is the most traditional one, during which Auto Levels and Total Station are mainly used. It was implicated widely in The German TVE Line and Shanghai Maglev Line. Optical measurement can directly measure and thereby evaluate the alignment of the guideway. With the increasingly popular application of modern photoelectric equipments, the technology and precision of photoelectric equipment has become increasingly perfect. Embedded with high performance computers, modern measurement instrument processes data with its program in measurement. These techniques has simplified the usage of these instruments and increased measurement precision as well, making it applicable to all sort of measuring geological features and environments. But its basic principles are still routed from optics, in other words, it reads related data by the transmission and reflection of light outside. The principle of this kind of method is relatively simple, the precision can entirely fulfil the requirements of the maglev guideway measurement, of course we should take into account climatic data (i.e. temperature, atmospheric pressure, humidity and earth curvature convert coefficient).

Optical measurement is usually used to determine the alignment in a wide section range. The space curve of the maglev track is complex and usually needs to be measured in both vertical (Z-direction) and horizontal(Y-direction) directions. Measurement at vertical direction get the condition of the alignment changes in Z-direction as well as horizontal one for Y-direction. Before the measurement on the track of each girder, what we should do is get the coordination of track measurement point from the fix measurement point on the ground besides the track. So, in the early stage of the measurement, we take our efforts into the investigation and selection of fixed reference points, as well as the supplementation or resumption of the measurement points destroyed by construction and nature. How to choose the measurement points for our use is more important. In the construction phase of Shanghai Maglev Line, we took the centre of the location pin hole in the joint unit as the measurement point to determine the altitude of the guideway. However, the hole was filled after the construction and made it impossible to serve as a measurement point. To solve this problem, special tools should be taken at the beside these guideway function unit immediately, with these

tools we can lead the coordination to the top of the guideway for simplify measuring .

Figure 1: Measurement beside the track in daytime

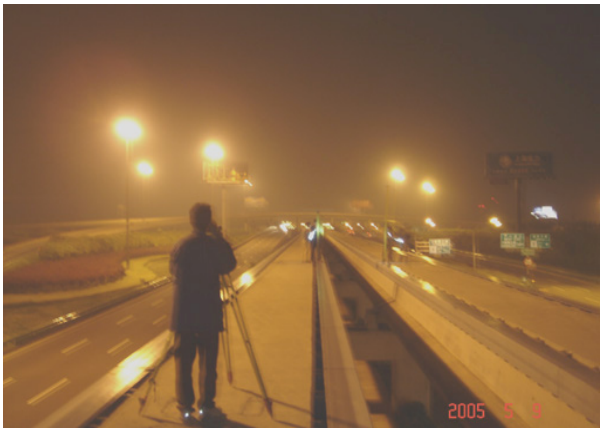

Figure 2:Measurement on the track at night

Although optical measurement is effective to determine long wave defection, but it is environment related. Due to special features of the maglev guideway, measurement is always conducted at high altitude in open fields. For commercial line like Shanghai Maglev Demonstration Line, measurement work on guideway can merely conduct at night in the time of no operation. Therefore, safety factor should be considered carefully during detailed management.

The so-called mechanical measurement is an auxiliary method for direct measurement of guideway components by mechanical devices, and usually conducts measurement to short wave defection of the guideway. This is also based on the fundamental requirements of guideway measurement. In actual maintenance work of Shanghai Maglev Line, we made a lot of temporary devices for measurement and with which to confirm the relations between stators, functional units and girders. Mechanical measurement is necessary particularly after adjustment of the girders. Although we can use optical measurement to accomplish the task also, mechanical measurement is a more convenient method. Considering the complex indoor evaluatuon after optical measurement, it is more effective to read the measurement results directly from the mechanical devices on-site. Therefore, mechanical measurement is more popular for short wave defection checking.

Both optical and mechanical measurement of the guideway should be applicated without maglev system operation. In order to get the real guideway alignment with trains running on, the factor of vehicle load should be considered into evaluation with variety of theoretical formulas and practical experience so as to get the guideway alignment under operation condition, However, there are still some uncertainness in the result getting in this way, for lacking of prove by long term practice.

With the development of electric technology, measurement methods have been developed with electrical equipment, triggering a heated discussion about maglev transrapid measurement by the means of electrical equipment. The methods adopted currently in Shanghai Maglev Line is to use the electrical equipment mounted on the vehicle to conduct on-line measurement for the guideway. With the support of relevant hardware and software, GMS system for short wave measurement has developed into a higher level on German TVE Line. The experience on German TVE Line was also applied to Shanghai commercial line and was proved to be effective.

The greatest advantage of GMS lies in the fact that it is an online system which can directly reflect true working statues of the guideway when vehicles are running on it. Moreover, automatically electronic measurement also relieves engineer from burdensome measuring tasks outside, the evaluation indoor are easier than before.

Currently, by the cooperating of Chinese and German, a long-wave measurement system named H-signal has been developing and testing now, which has already put into commissioning. This system collects the actual movement of the vehicle guidance and levitation modules by acceleration sensors and makes off-line data evaluation to get the actual “shape” of the track with the help of real-time recording of the gap between the guideway and the guidance/levitation surface. It can directly indicate the status of the long wave. In the experimental application of this system, we compare the alignment before and after girders-adjustment, the data shows the system is quite reliable. This measurement method is in the developing period, we can say it is the method with bright future, of course on the base of further research and developing. It's the only way for us to take the alignment measurement to realize the guideway maintenance on longer maglev line in the near future.

The three methods upwards are the main methods for current maintenance of maglev track, We at-

tempted to use the GPS measurement and the high precise robot measurement to ensure the nicety of the control points, However, It only could be used as a temporary assistant measure since we still no sure whether it can reach the precision of maglev measurement or not.

Summarize the characteristic of the three kinds of measurements：

– **Optics measurement:**
Adaptability: *long wave.*
Advantage: *Traditional and developed with high reliability.*
Disadvantage: *Measurement result only reflects the guideway without the load of vehicle. The application work outside is quite hard and affected by operation.*

– **Mechanical measurement:**
Adaptability: *short wave.*
Advantage: *Application easily and convenient.*
Disadvantage: *only can get short wave in some appointed location.*

– **Electrical measurement:**
Adaptability: *short wave & long wave.*
Advantage: *the alignment of guideway with the vehicle can be got online.*
Disadvantage: *The stability of new technology not be proved and need verified by other method on site now.*

6 THE GIRDERS/ADJUSTMENT

When we get the guideway evaluation of long wave and short wave by measurement and analysis, we will find the points of problem on the track. The only way to solve these problems is application of girders-adjustment. Most of the short wave problem need adjust the component within one girder only, but for long wave problem, several girders will be adjusted with hard work on the track.

Normally, we do little adjust on the stator pack or function unit to satisfy the tolerance of NGK and offset. The stator packs are installed on the function units by high strength blots and fixed by the mode of coattail slot and key for redundancy. The adjustment should be satisfied by the NGK and offset at same time. Using the mechanical measurement device to measure and adjust time after time until to satisfy. The crane device should be used because the stator pack and function unit are steel components with several hundreds kg.

The long wave is more complicated. The first mission was how to choose the serious section when we evaluated the data from the first measurement phase in Shanghai. The workload is depends on how to choose the section with long wave problem because nearly the whole guideway had long wave problem through four years sedimentation. It was reliable that we chose the guideway section where the train speed over 200 km / h and the long wave problem with large inflexion by the experience in Shanghai. We introduced the concept of girder-NGK to describe the condition of relationship of conjoint girders. We can not adjust individual girder without consideration its conjoint girders, each joint position should be relatively smooth and avoid large inflexion.

The adjustment of girder is designed to realized by adjust the bearing, and the bearing can be adjusted on three dimension. The adjustable bearings in Shanghai line can be adjusted up 20 mm, down 10 mm and 20 mm for left or right. According to the experience in shanghai line, this data limitation can be enlarge a little bit in the future to fit more adjustment scope for optimize.

Figure 3: Bearing adjustment

The adjustment on bearing is only several millimetres, but for the girder of huge buster is inconvenient. Moreover, the adjustment should be done on the high top of support column without operation in the night. We adjust the bearings on the scaffold and platform near the support by using the high tonnage jack to peak the girder, the spring quantity also should be considered. The girder on curve line is unusual because we should adjust the four bearings simultaneously to overcome the excursion danger caused by barycentre. We should do the measurement and adjustment at same time until to satisfy the short wave of girder before release the guideway for operation.

However, we still had a problem how to ensure the force proportion of four bearings on one girder. This point was a serious problem during the construction phase; it is more difficult to ensure the force proportion for adjustment of bearings on destined data after sedimentation. At present a kind of hydraulic jack controlled by computer was used and it not only can adjust the high accurately but also

show the force, this way give us a better means of control the adjustment process. From now on we still did not use this kind of jack and we should try it on practice in future to accumulate experience for guideway maintenance.

7 SUMMARY

After these several years of operation in Shanghai line, we think that measurement is necessary and important for maglev system, the cost and effect would be different by use the different kind of measurements, the strategy can be discussed. Normally, we measure and analysis the short wave by the means of GMS to get the location information. And then we will arrange the mechanical measurement on the position for affirmation, adjust it after evaluation to optimize the short wave. We could choose possible trouble section in maintenance on scheduled to measure it by means of optic and then collect the data to evaluate on the vertical and horizontal for judge the long wave problem and adjust it. If the vehicle perform is bad such as obvious swag or bump in somewhere, we would take unscheduled measurement and adjustment to optimize the alignment of the guideway.

We have got many experiences through practice in Shanghai. However , it was pity that we did not measure the guideway completely immediately after construction induce we had no basic reference data after the change of guideway, it was hard to compare for adjustment and caused short section optimize is not good on longer section scope. Herein, we should measure the guideway and establish database during and after construction immediately in the new project, So as to supply basic data for maintenance during operation, and enhance the maintenance technology through practice.

Both of the technology of measurement and maglev system is developing, So the measurement and control of maglev guideway are developing also. We believe that the measurement and adjustment of maglev guideway will be more scientific and convenient through our endeavour in the near future, and the stable and safety guideway will provide maglev passengers with more perfect transportation service.

8 REFERENCES

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