Long Wave Guideway Contour Monitoring

No. 113
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ABSTRACT: The accuracy of the real rail position of the guideway has an high importance for the ride-comfort and for the availability at high - speed railway systems. One possibility to check is a regular geodesic measurement of the track. The electronic observation of the long-wave guideway contour, described in this article, enables the recognition of errors at guideway components and of settling at pylons within the normal operation and under load of the vehicle at the first public maglev line in Shanghai.

1 INTRODUCTION, BASICS

The Transrapid System realizes non-contact support and guiding of the vehicle by means of electro-magnets. To achieve this, the reaction surfaces statorpack and guidance rail for the components of the support and guidance system are integrated in the guideway, see Figure 1.

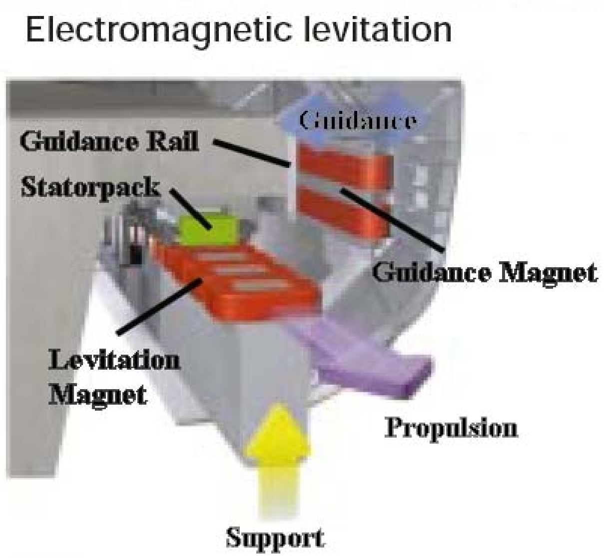


Figure 1: Electromagnetic levitation and guidance

At the public service route in Shanghai an elevated guideway type in a hybrid construction style with beams of a usual lenght of about 25 metres was realized, with 3 metre long function modules made of steel being fixed to the concrete main support unit. The modules support the statorpacks and form the guidance rail used for the lateral guidance. Figure 2 shows a picture of the guideway in Shanghai during construction before all modules had been fitted.

Figure 2: Transrapid Guideway Shanghai

In the maglev vehicle the distance between the magnets and the reaction surfaces is registered for magnet control with non-contact displacement sensors. This control principle also allows determining the position of the reaction rails (stator and guidance rail) in the short-wave sector. For monitoring divergences in the guideway geometry an online operating Guideway Monitoring System (GMS) has been installed in 2 vehicles. With the help of vehicle own gap sensors the offset changes are monitored continually between consecutive statorpacks and guidance rails and independently of the speed.

The public service track in Shanghai links Pudong International Airport with Long Yang Road Station on the fringe of the Lujiazui Finance Centre. The track runs through the alluvial plain of the River Yangtze. The layers of soil consisting of young gravel and soft clay are likely to cause buildings to subside. The experience of the Chinese companies involved was considered in a constructive way, which led to the forming of deep basements on drilled piles in some areas as well as to the construction of vertically adjustible beam bearings, for example, in order to level out later subsidences.

Subsidences at single girders of the Transrapid guideway have - besides possible effects relevant to the operation (e.g. switching off of magnets; contact of skids with the guideway) - effects especially on those relevant to the ride comfort, as the unequal subsidence of the two shafts of a pylon can also induce lateral divergences, which, in a rapid transition, cause an inconvenient sideway movement of the vehicle cabin. By calculation of a "long-wave guideway contour signal", using data which can be measured with a sensor package consisting of the vehicle gap sensor (mentioned above) and an additional acceleration sensor, it is possible to identify, survey and readjust those sections. Moreover, precautionary maintenance is possible through long-term cyclical monitoring and through comparing referential data as well as monitoring positional corrections carried out earlier.

2 CHARACTERISTICS AND POSSIBILITIES OF DETERMINING THE LONG-WAVE GUIDEWAY CONTOUR

The "long-wave" guideway performance is characterized by effects referring to the length of one or more than one beam. These effects are

- Deformation of the beam under operational load
- Changes of the angle at the beam joints
- Subsiding pylons

Figure 3 shows the different effects:

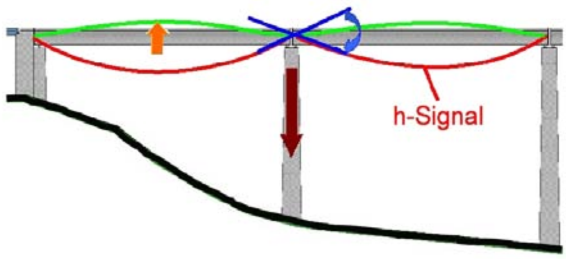


Figure 3: Parameter of „long wave“ guideway contour

The figure shows the course of an elevated guideway with beams of the single-span type. The red contour describes the course of the deflection of the guideway beams under the operational load caused by the vehicle. The green contour shows the course of the guideway without this operational load (pre-curvature of the beams). This pre-curvature changes due to the temperature and consequently, the absolute dimension of the deflection under the operational load also changes. Another significant sphere of influence on the long-wave guideway contour is the angle at the beam joint (inclination change criterion, blue lines). The maximum gradient change at the pylon belongs to the determining quantities in designing maglev guideways. The vertical brown arrow eventually describes the lowering of a girder in the event of a subsidence at the pylon.

The classical geodesic survey of the guideway with the help of optical devices has also been applied to maglev guideways for years. The application of modern equipment such as total station and computer assisted surveys and evaluations enable us to determine the space curve of the guideway over long sections with very high accuracy. The bases are the ground surface and the track platform, respectively, with reference points being fixed at the girders (targets, height bolts). Figure 4 shows measurement works at the guideway in Shanghai.

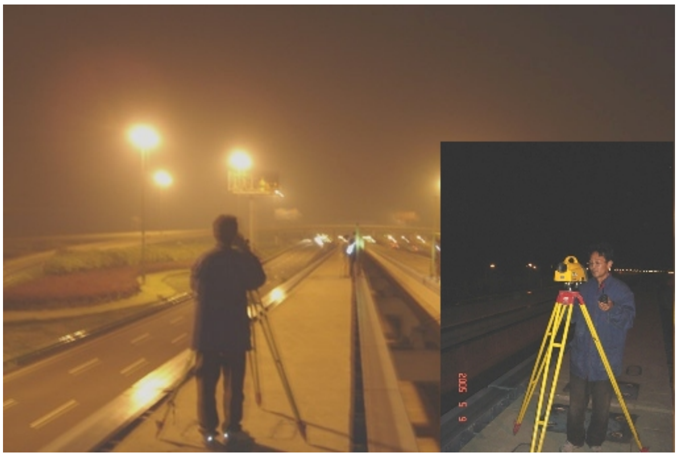


Figure 4: optic / geodesic measurement

If you have to stand on top of the guideway, a geodesic measurement is only possible between operational times, that means on the commercially operating track in Shanghai during night hours only. Measurements on the ground can also be carried out during service times, but in all cases the position of the guideway will be determined when it is not under operational load of the maglev vehicle (green contour in Figure 3). Geodesic measurements require a lot of personnel as well as time, a periodic monitoring of all track sites at short intervalls is therefore not possible.

The automatic determination of the "long-wave" course of the function levels at the beam and their evaluation in a diagnostic system requires an electronic illustration of the guideway contour, in which the relative movement of the measurement vehicle to the guideway is suppressed in the evaluation. The determination of the guideway contour under the operational vehicle load (red contour in Figure 3) is made possible through a sensor package at the maglev vehicle.

Figure 5 shows the movement of a sensor package at the vehicle during operation on the guideway.

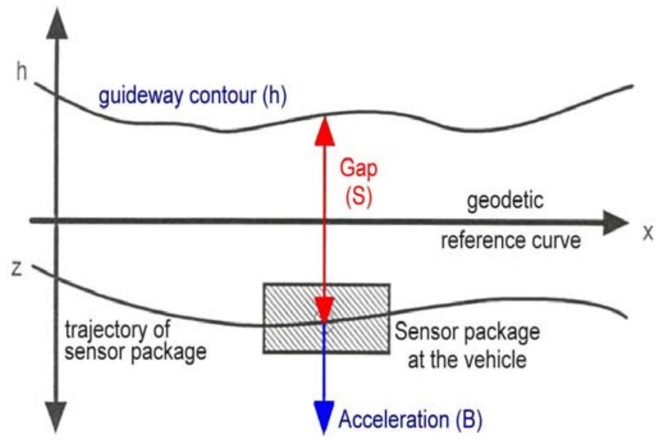


Figure 5: electronic measurement

The given guideway contour is represented by the letter h. The sensor measures the air gap S between the sensor package and the guideway contour (red arrow). The sensor package in its turn describes the track curve z during measurements based on vehicle movements relative to the guideway. This movement is now measured by a highly accurate acceleration sensor (blue arrow, acceleration B). The block diagram of the subsequent evaluation with formation of the h-signal is shown in Figure 6:

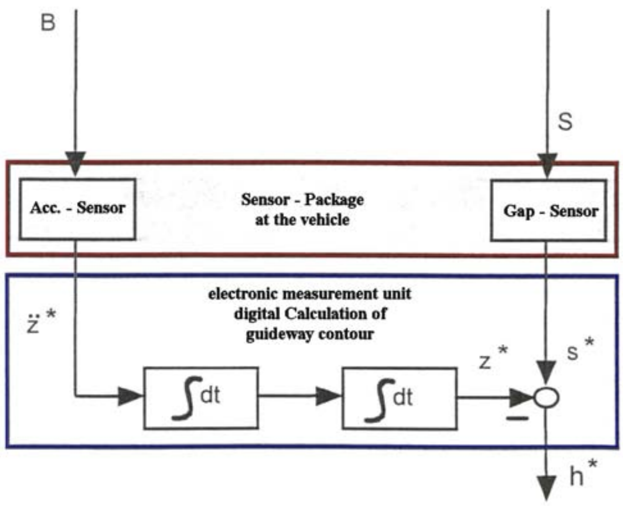


Figure 6: electronic measurement

Input values of the electronic measurement unit are the air gap S and the acceleration B of the sensor package consisting of a gap sensor and an acceleration sensor. From the acceleration the course of the sensor package is formed, that is the track curve z, through a mathematical double integration. This course is then subtracted from the measured gap, and the result is the guideway contour h rectified by the vehicle movement (Equation 1).

$$h(t) = S(t) - \iint B(t) \qquad (1)$$

The (theoretical) evaluation steps mentioned above presuppose an ideal sensor signal not existing in reality. Crucial for the quality of the measured guideway contour is the quality of the acceleration signal and its further processing. The mathematical integration of a measurement signal is liable to drift effects due to the integration constants. These effects grow with a longer integration time. In the evaluation process, possible offsets that might cause drift effects are suppressed by a high-pass filter. Phase faults due to the filtering process have to be rectified subsequently.

In order to keep the integration time as short as possible, a higher velocity is necessary for the measurement. The qualification of the measurement system has demonstrated that a minimum measurement speed of about 100 k.p.h. provides highly accurate evaluation rates (deviations < 1 mm) for the monitoring of about 200 metre long sections (corresponding to 8 beams with a standard field span of 25 metres for the single-span beam). Because of the necessary high-pass filtering process, measurements over very long distances are on principle not possible unlike in geodesic procedures. But for data monitoring of deviations relevant to operation and ride comfort this is not necessary.

3 DEVELOPMENT OF THE MEASURING SYSTEM FOR THE DETERMINATION OF THE LONG-WAVE GUIDEWAY CONTOUR

In cooperation with the companies IABG, SMTDC in Shanghai and Thyssen Krupp Transrapid a measuring system for determining the long-wave guideway contour has been qualified. One objective in the development of the measuring system was its integration into existing diagnostic systems. As 2 vehicles had already been equipped with the Guideway Monitoring System for monitoring short-wave offset changes, a large number of prerequisites had been met beforehand, such as the gap measurement and the very precise determination of track location, in order to determine the long-wave guideway contour as well. To achieve this, an acceleration measurement at the levitation magnets and guidance magnets were added to the system, Figure 7 shows the installation of the acceleration sensor at the levitation magnet.

Figure 7: acceleration sensor at the levitation magnet

The block diagram, Figure 8, shows the signal path of the additional acceleration signal.

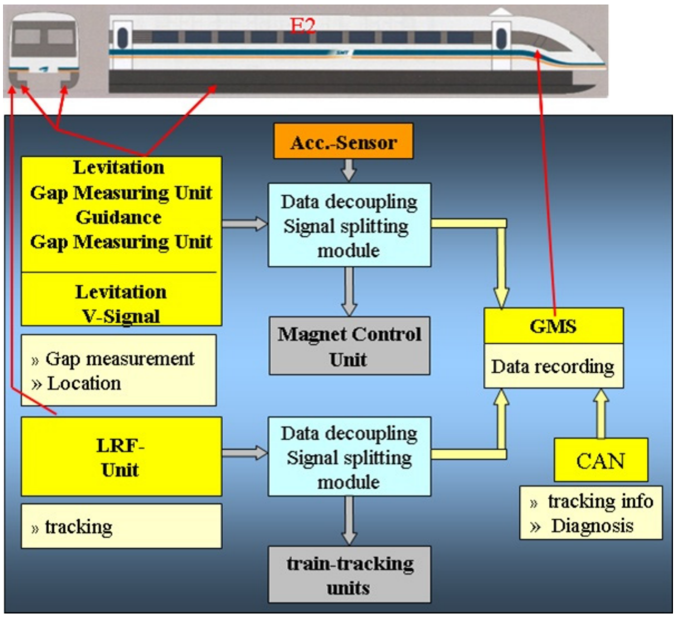


Figure 8: Block Diagram GMS

The GMS uses the original gap measurement units of the vehicle for measuring the gaps. It was possible to connect the acceleration sensors in each case to the existing signal splitting module between the gap sensor and the magnet control unit. None of the existing signal paths suffered restriction through this update.

Another objective was the – where ever possible - optimal integration of the data acquisition process into the daily service operations. Instead of separate

measurement runs normal passenger service runs were to be used for gathering data. As there would not be a constant running speed measures had to be taken to set up the necessary preconditions in the evaluation for the digital filtering of the signals.
In order to gather the data a member of staff is on-board during one operating cycle (Long Yang Road Station – Pudong Airport Station – Long Yang Road Station) and starts the measurement. To do this, the automatic online offset monitoring is interrupted for this running cycle. After the measurement run the data are stored in a mobile data medium, with the subsequent evaluation being done offline on the Guideway Diagnostic Server.

The recording of the data is done at a constantly high data rate, all further signals that are necessary for the evaluation (diagnostic and locating information) are recorded at the same time. These time-based unprocessed data signals thus include varying numbers of data points per track increment, which are dependent on the running speed. In this signal neither a low-pass nor a high-pass filter process at a constant filter frequency is possible. In the evaluation, the data record will be resampled, with the current running speed determining the amount of the resulting scanning rate. In this way we obtain an output signal, which is no longer based on time but shows a distance-dependent and speed-independent number of data points per increment of the distance travelled. All further filter processes and data preparations will be applied to these distance based signals, thus enabling work with constant basic frequencies. The signals are high-pass filtered with a filter frequency that corresponds to a guideway section of 200 metres, in order to eliminate the drift of the acceleration signals for the subsequent double integration. To avoid phase faults between the signals, the gap signals will always be treated equally. After subtracting the track curve z (formed from the double integration of the acceleration signal) from the gap signal S, the guideway contour signal h is available. The resampling process to achieve a distance-based representation will then make it easy to attribute this result signal to each guideway location.

Figure 9: Measurement channels relatively to the guideway

The guideway in Shanghai consists of two pylons with a single foundation, which are joined at the top by a cross beam. Above the cross beam, the two single tracks A and B rest on the beam bearing. During an operational cycle to determine the long-wave guideway contour, two separate measurements of jouneys on track A and on track B will be recorded. The different running directions of these two processes will be rectified automatically. The evaluation of single measurements (only one track) is also possible. Figure 9 shows a picture of the guideway at the public service route with the recorded signals.

Each measurement records the signals of the two guideway tracks on the levitation level (Lev left; Lev right) and on the guidance level (Gui left; Gui right). Appropriate balancing and visualisations of the resulting data records help to determine different effects on the long-wave guideway contour (Figure 10).

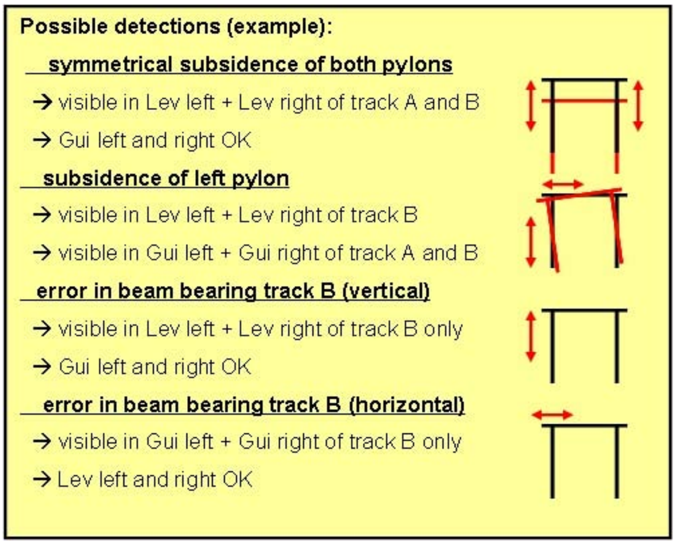


Figure 10: Signal evaluation

A symmetrical subsidence of the foundation leads to a deviation in the signals of the levitation level on tracks A and B, but usually this effect does not occur at both sides absolutely regularly. This, however, leads to lateral jerks because of the height of the pylons and the resulting lever law, having thus an immense effect on ride comfort. This scenario finds its representation in the results as a deviation from the design position on the levitation as well as on the guidance level. Beside these comfort deficiencies due to subsidences, the long-wave monitoring of the guideway can also help to identify faults in the horizontal and vertical beam bearings. In this context the results of only one track will be concerned.

Figure 11 visualizes the results of a complete operational cycle.

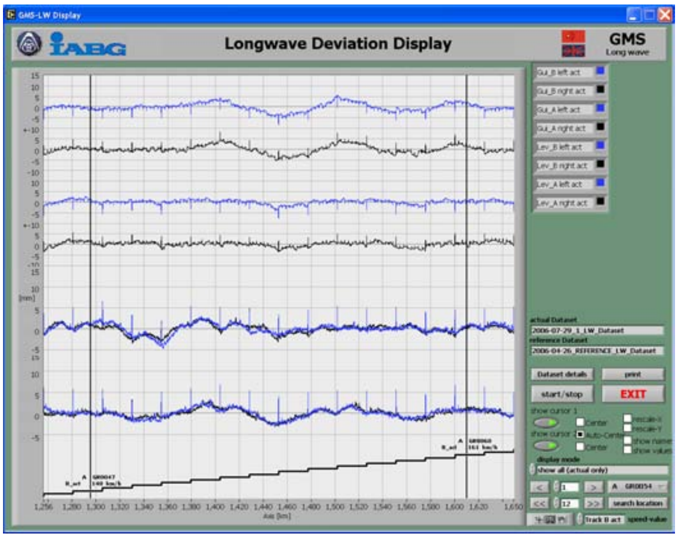
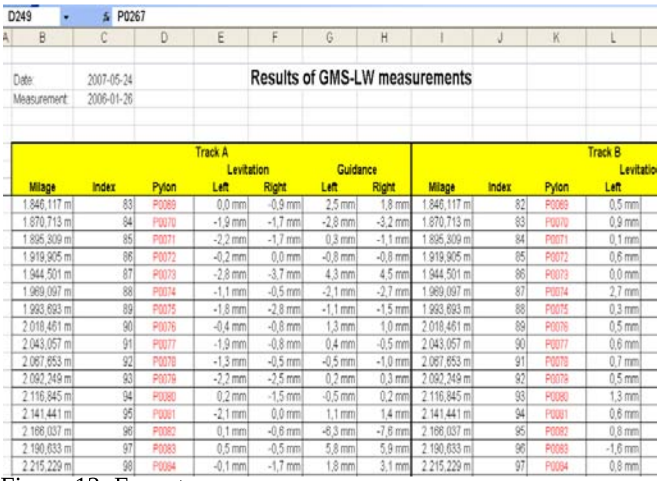


Figure 11: Evaluation software

All signals are displayed in relation to the guideway location and synchronically to each other. In the upper part, the lateral position of tracks A and B is viewed from the top, below this, the signals are displayed in vertical direction left and right, respectively. Finally, some information is given in the lower part of the display on the guideway location and on the speed of the measurement process at this location. With the help of measurement cursors you can scroll through the signals, while search functions offer direct access to guideway locations on display.
In addition to this display one have the option of loading another measurement run in order to examine a reference run through direct comparison.

For adjusting beams, especially the data above the pylon are of significance. To extract these data, the signal is again smoothed in an export function and reduced to one representative value per pylon (analogous to the result of a geodesic measurement). These data will then be entered into a table (Figure 12) and made available for further processing.



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Date: 2007-05-24
Measurement: 2006-01-26

Results of GMS-LW measurements

Track A							Track B			
			Levitation		Guidance					Levitatio
Milage	Index	Pylon	Left	Right	Left	Right	Milage	Index	Pylon	Left
1.846,117 m	83	P0069	0,0 mm	-0,9 mm	2,5 mm	1,8 mm	1.846,117 m	82	P0069	0,5 mm
1.870,713 m	84	P0070	-1,9 mm	-1,7 mm	-2,8 mm	-3,2 mm	1.870,713 m	83	P0070	0,9 mm
1.895,309 m	85	P0071	-2,2 mm	-1,7 mm	0,3 mm	-1,1 mm	1.895,309 m	84	P0071	0,1 mm
1.919,905 m	86	P0072	-0,2 mm	0,0 mm	-0,8 mm	-0,8 mm	1.919,905 m	85	P0072	0,6 mm
1.944,501 m	87	P0073	-2,8 mm	-3,7 mm	4,3 mm	4,5 mm	1.944,501 m	86	P0073	0,0 mm
1.969,097 m	88	P0074	-1,1 mm	-0,5 mm	-2,1 mm	-2,7 mm	1.969,097 m	87	P0074	2,7 mm
1.993,693 m	89	P0075	-1,8 mm	-2,8 mm	-1,1 mm	-1,5 mm	1.993,693 m	88	P0075	0,3 mm
2.018,461 m	90	P0076	-0,4 mm	-0,8 mm	1,3 mm	1,0 mm	2.018,461 m	89	P0076	0,5 mm
2.043,057 m	91	P0077	-1,9 mm	-0,8 mm	0,4 mm	-0,5 mm	2.043,057 m	90	P0077	0,6 mm
2.067,653 m	92	P0078	-1,3 mm	-0,5 mm	-0,5 mm	-1,0 mm	2.067,653 m	91	P0078	0,7 mm
2.092,249 m	93	P0079	-2,2 mm	-2,5 mm	0,2 mm	0,3 mm	2.092,249 m	92	P0079	0,5 mm
2.116,845 m	94	P0080	0,2 mm	-1,5 mm	-0,5 mm	0,2 mm	2.116,845 m	93	P0080	1,3 mm
2.141,441 m	95	P0081	-2,1 mm	0,0 mm	1,1 mm	1,4 mm	2.141,441 m	94	P0081	0,6 mm
2.166,037 m	96	P0082	0,1 mm	-0,6 mm	-6,3 mm	-7,6 mm	2.166,037 m	95	P0082	0,8 mm
2.190,633 m	97	P0083	0,5 mm	-0,5 mm	5,8 mm	5,9 mm	2.190,633 m	96	P0083	-1,6 mm
2.215,229 m	98	P0084	-0,1 mm	-1,7 mm	1,8 mm	3,1 mm	2.215,229 m	97	P0084	0,8 mm

Figure 12: Export

4 OPERATIONAL APPLICATION OF THE MEASURING SYSTEM AT THE PUBLIC SERVICE ROUTE IN SHANGHAI

As the incident of subsidences due to ground conditions had been considered beforehand, beam bearings were developed by the Chinese partners, which allow vertical and horizontal movements and thus making re-adjustments possible. To achieve this, the beam is lifted by presses so that the bearing can be adjusted (Figure 13).

Figure 13: Adjustment of bearing

Most time subsidences only occur at single pylons, which are difficult to identify with a geodesic measurement, since there is no information about the exact guideway location without a direct measurement in the vehicle and since a geodesic measurement itself is very time consuming.

The electronic determination of the guideway contour through isochronously recording data during regular passenger services now enables us to evaluate the data after the measurement and to determine those guideway locations exactly that require corrections, so that these corrections can be made during the nightly maintenance shift. In each case an additional geodesic measurement was taken at the guideway location in question as a check-up.

On the following operational day the completed works could be monitored without delay with the help of the measuring system. Figure 14 is a display of the situation before / after.

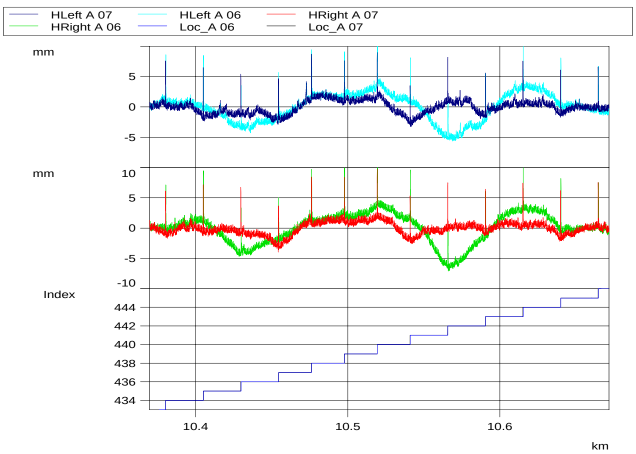

Figure 14: Result of girder adjustment

The green and light blue graphs show the results of a measurement run left and right prior to the adjustment. A distinct lowering is visible at two locations. Thanks to a re-adjustment of the vertical position at the transitions of the guideway beams a distinct smoothing was achieved in this guideway section. This distinctly improved the ride comfort at these locations (red and dark blue graphs).

5 OUTLOOK

Thanks to a close cooperation and excellent team-work of German IABG and Chinese SMTDC it was possible within a short period of time to install and qualify a measuring system in order to determine long-wave guideway deviations at the public service route in Shanghai and as a consequence improve the ride comfort through re-adjustment measures.

Future longer service routes, more than others, will require an electronic determination of the long-wave guideway course isochronous to operational services as a cyclicle - and feasible - monitoring measurement. The acquisition of reference data records after the completion and the geodesic check-up of such a new guideway also offer the possibility of an automatic evaluation by comparing subsequent measurements with this referential state of being.

For the absolute measurement of the guideway over very long distances, geodesic measurement processes will still be necessary, in the field of distances relevant to comfort and operational issues, however, the electronic determination of the guideway contour can be made use of in a significantly more efficient way and will comply better with operational services.

6 REFERENCES

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