EBERHARD GROSSERT, D. Sc.
GP Dr. Grossert Planungsgesellschaft mbH
Inselwall 14, 38114 Braunschweig, Germany
Meinekestr. 24, 10719 Berlin, Germany

Traffic Planning
Preliminary Communication
U. D. C.: 625.111
Accepted: Mar. 14, 2003
Approved: Apr. 28, 2003

TRANSRAPID SHANGHAI
Construction of the First Commercial Operational Line

ABSTRACT

The system technique, the routing of the track, the used guideway constructions as well as their production plants are described in this report. Parts of the planning activities will be explained which are required on the German side to cover the interface between German delivery parts and Chinese planning and production activities. Information about the absolutely short realization time for the erection of the guideway constructions will be given.

KEYWORDS

TRANSRAPID Shanghai, track routing, guideway constructions, production plant, dates

1. INTRODUCTION

More than 5500 track kilometers are so far identified worldwide as possible TRANSRAPID lines. The interest in the German magnetic technology of the TRANSRAPID achieved a new high level. Since December 2000 in Shanghai the first commercial TRANSRAPID operational line is under construction. Laid out as an Airport link between the International Airport Shanghai Pudong and the Long Yang Road Underground station (Fig. 1).

Since August 2000 the preliminary project planning runs for a high speed maglev route in the Chinese economy metropolis Shanghai. By the end of 2002, after approx. 700 days of planning and realization, the TRANSRAPID should connect the new major airport Pudong with the Long Yang Road Station near the city centre of Shanghai on a double-track guideway of approx. 30 km and an operation velocity of 430 km/h. The official signing of the contracts between the Chinese government and the consortium of TRI, ThyssenKrupp and Siemens for this first commercial route of the TRANSRAPID occurred on 23rd January 2001. Subsequent to successful processing of the present project a decision should be taken in China in favour of the long connection Shanghai - Beijing (1140 km) as

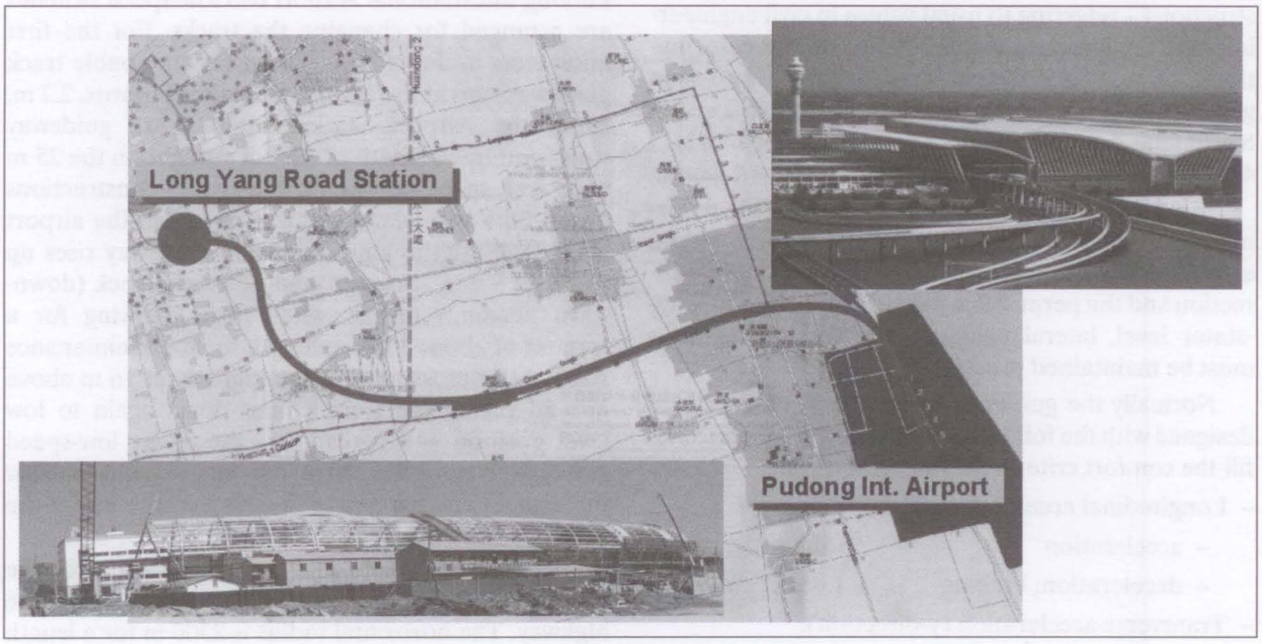

Figure 1 - Overview

well as of the continuation of the present airport line as far as Hangzhou (180 km).

2. GENERAL SYSTEM CHARACTERISTICS

The TRANSRAPID levitates contactless along the guideway at speeds of up to 250 km/h in built-up urban space, or even 550 km/h in the open. The gap between the vehicle and the support/guidance construction is only approx. 10 mm. Contrary to the propulsion principle of conventional traffic systems, the primary parts of the propulsion system, the stator packs with their windings, are attached on both sides of the girder constructions in the cantilever (Fig. 2).

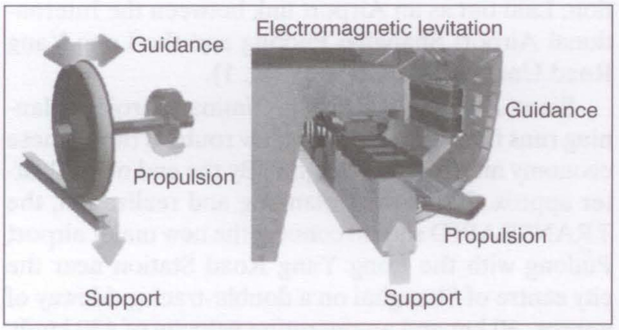

Figure 2 - Levitation and propulsion

In the Transrapid technology the functions of wheel and rail are replaced by a non-contact electromagnetic levitation and propulsion system.

There are substantial advantages: less dead weight, no contact, no friction, no noise from this source. Essential parameters for the design of the guideway constructions - referring to usual values in civil engineering - are the low permissible tolerances and deformations. In vertical-direction (z-direction) a two-span guideway girder with a span-length of approx. 2 x 31 m has to limit deformations as a result of live load $\leq l_{sys}$ / 4 800 = 6.5 mm and/or $\Delta T_{to-tu} \leq l_{sys} / 6\,500 = 4.8$ mm.

In addition, the supplementary permissible deformation values of the substructures and the y-direction, as well as the gap width at the guideway joint in x-direction and the permissible misalignments in the long--stator level, lateral guidance rail and gliding strip must be maintained precisely.

Normally the guideway construction of tracks are designed with the following comfort limit values to fulfill the comfort criteria for the passengers:

- Longitudinal acceleration (x-direction):
  - acceleration $\leq 1.0 m/s^2$
  - deceleration; braking $\leq 1.0 m/s^2$
- Transverse acceleration (y-direction):
  - free lateral acceleration 0.5 - 1.0 m/s^2
- Vertical acceleration (z-direction):
  - hump / crest $\leq 0.5 m/s^2$
  - sag / valley $\leq 1.0 m/s^2$
- The aim is to achieve a balanced lateral acceleration for the normal travel profile.
  - maximum transverse gradient 12°

Technically the system allows larger limit values.

For the determination of suitable protective measures, the following route alignments are separated from safeguarding aspects - independent of construction:

- at-grade guideways:
  1.25 m < gradient height H ≤ 3.50 m
- elevated guideways:
  3.50 m < gradient height H ≤ 20.00 m
- guideways on bridges

The level of the guideway in relation to the ground may be designated as elevated position, at-grade position or cut position.

An operational line of the single- or double-track guideway is joined from different guideway modules. The guideway modules were chosen in accordance to topography, technical and ecological limitations as well as to optimum economical solutions.

3. TRACK ROUTING

The TRANSRAPID track in Shanghai starts at the newly built Pudong International Airport. The entire 30 km between the Airport Station and the Long Yang Road Subway Station are constructed as double-track guideway with a center-to-center distance of 5.1 m. Behind the TRANSRAPID-Station Pudong International Airport two low-speed switches are arranged for changing the tracks. For the first kilometers in direction to Shanghai the double track guideway runs at low level in a height of approx. 2.7 m. From the Airport Station Pudong the guideway runs for a track length of 8.5 km straight on the 25 m wide free space between the elevated constructions of the both three-lane highway to / from the airport (Fig. 3). Near the km 4-mark the guideway rises up to about 8.5 m above ground, the right track (downtown heading) meets switch no.7, allowing for a turnout of about 3 km in length for the Maintenance Area. After crossing over the highway at 16 m above ground this single track comes down again to low level position and spreads via the 3-way low-speed switch in front of the 220 m long maintenance hall for three maintenance and/or washing tracks inside the hall.

Behind the turnout to the Maintenance area the guideway runs further between the both tracks of the highway. The horizontal radius is 2300 m for a length of 2 km with a maximum cant of the girder surfaces of

Figure 3 - View onto the double track guideway between the six-lane highway

Project data

track length	30 km double track
center-to-center distance for track sections of approx. 27.4 km	5.10 m
surface height of the girders for track sections of approx. 20 km	8.00 – 11.50 m
min. / max. height of the space curve above ground in the main tracks	2.80 m / 13.50 m
hybrid guideway girder type I, L = 21.7 - 24.8 m	approx. 2500 pcs.
hybrid guideway girder type II, L = 12.4 m	approx. 50 pcs.
guideway girder on bridges, L = 6.2 m	approx. 60 pcs.
switches, L = 78.4 m	8 pcs.
substructures total	approx. 1380 pcs.
track to the Maintenance Center	3 km single track
stations	2
number of vehicles	3 vehicles with each 6 sections
max. operation speed	430 km/h
travel time	8 min
minimum distance of the vehicles	10 min
daily operation time	18 hours

$\alpha = 12°$. Then a long almost straight part follows with horizontal radii from $R_H = \infty$ or 4000 m and 8000 m. At track kilometer 21.3 - about 8.5 km away from the airport - the routing changes from between the highway tracks to the north side of the straight six-lane highway and runs on for 10 or 11 km with a height of about 8 to 10 m above ground along the highway (Fig. 6). In this section of the track the maximum operational speed of 430 km/h is achieved. Then two mutual radii with $R_H = 4500$ m and $R_H = 1300$ m follows up to just before Long Yang Road Station. The gradient height of the double-track guideway rises up to 13.5 m above ground. Also in this area the guideway gets a cant of the girder surfaces of maximum 12°. Directly in front of the Long Yang Road Station in the height of 13.5 m a crossover - consisting of four switches - is arranged to change the tracks. The center-to-center distance to go into the platforms of Long Yang Road Station is here 12.1 m. After 8 minutes of levitation time arriving at the approx. 210 m Long Yang Road Station in Pudong, it is possible to go to the final destination in the hypermodern finance center Pudong or to go by subway to the old Shanghai on the opposite side of the Huangpu River.

4. GUIDEWAY CONSTRUCTIONS

Compatible to environment and economical, safe and fast – these are the qualities of the high-speed maglev system TRANSRAPID, reflected also in the design of the guideway constructions. Except of few scopes of application in the civil engineering in the field of industrial prefabrication, buildings are in general uniques. However, a track for application for the TRANSRAPID is a construction several kilometers long with single components recurring constantly. The systems engineering of the linear stator engine with unchangeable ranges as well as the "line construction" guideway needs to create individual guideway modules, arranged in accordance with topography for the entire guideway of a high-speed maglev operational line.

Figure 4 - Girder transportation

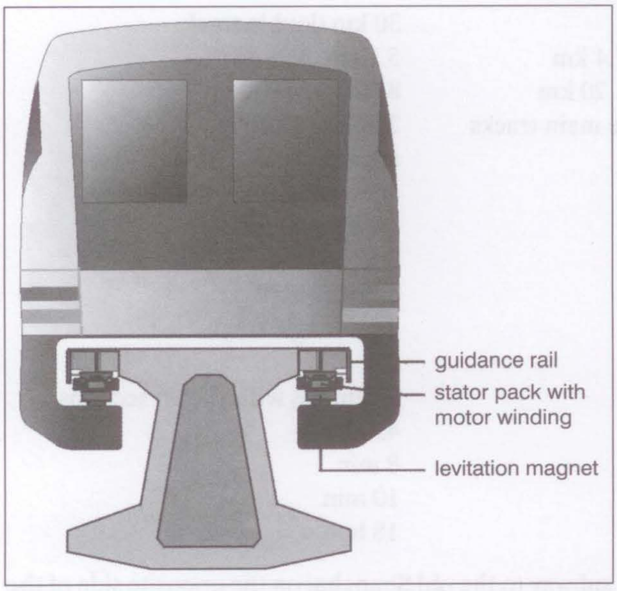

Figure 5 - Cross section

Figure 6 - Hybrid guideway girders along the track

It is to distinguish between girder guideways and plate guideways. The different guideway models will be applied depending on the height over ground or at special structures. Girder constructions with large span length and bearing on substructures with single foundations are inserted primarily at high gradients, plate constructions with strip foundation are inserted primarily in the case of low space curve situation. Instead of storing onto single or strip foundations, these guideway models can also be combined directly with special constructions (bridges, tunneling...). Guideway girders with a span length of approx. 12 m may be used economically in elevated position, at-grade position or cut position.

In longitudinal direction, the support spacing for the guideway girders is determined on the basis of the pole pitch of the drive systems and is a multiple of the stator pack length of 1 032 mm. A value of 24 times the stator pack length = 24,768 mm was defined as the standard span length for elevated guideway girders in the Shanghai project, irrespective of the material used for the girders. The span length can be reduced (or increased) by a multiple of the stator pack length or part of it in order to permit adaptation to route constraints.

The cross-section of the guideway girder results in the fastening of the specific operational components consisting of long-stators with windings, lateral guidance rail as well as gliding strip on top of the cross-section. The principle geometry of these elements is equal for all guideway constructions.

In the summer 2000 during the preparation of the feasibility study for the first application line in Shanghai, different construction types of guideway girders, extensively tested at the TVE test facility in Germany, have been presented to Chinese engineers. The Chinese delegation has decided in favour of the hybrid guideway girder. This type of guideway girder is as two-span girder with span lengths of approx. 31 m, developed by a German consortium consisting of the companies Max Bögl, Gebr. von der Wettern and Cronauer Beratung Planung in 1997 - 2000. The main structure of the German prototype girder is a monocellular box girder about 2 m high (Fig. 5). Over the supports cross beams extend from the girder sides to lead the high lateral forces in curve rides (Fig. 8) economically down to the substructures. The cantilever of the hybrid guideway girder - arranged at the girders upper side - consists of the function units with a length of approx. 3.1 m and are made of steel. At this function unit girder is fixed the levitation and guidance system of the TRANSRAPID with the system-immanent narrow tolerance requirements. A variant of the same pattern though 2 x 12.4 m in length and only 1.0 m high has also been designed in Germany.

These prototypes were the basis for the Chinese developments of the guideway girders. The monocellular box girder with cantilevers became to double-T shaped hybrid guideway girder with box girder section. The 2.8 m wide lower flange was complemented for the increase of the lateral stiffness of

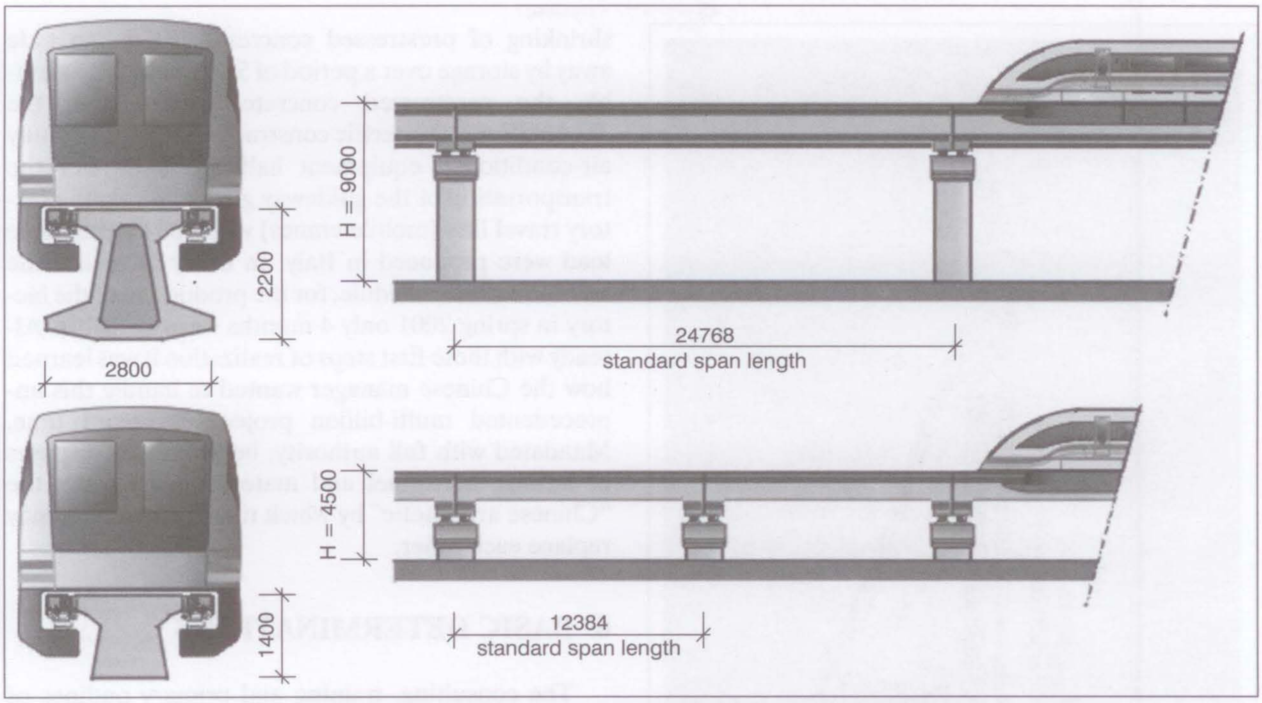

Figure 7 - Hybrid guideway girders of the Shanghai project

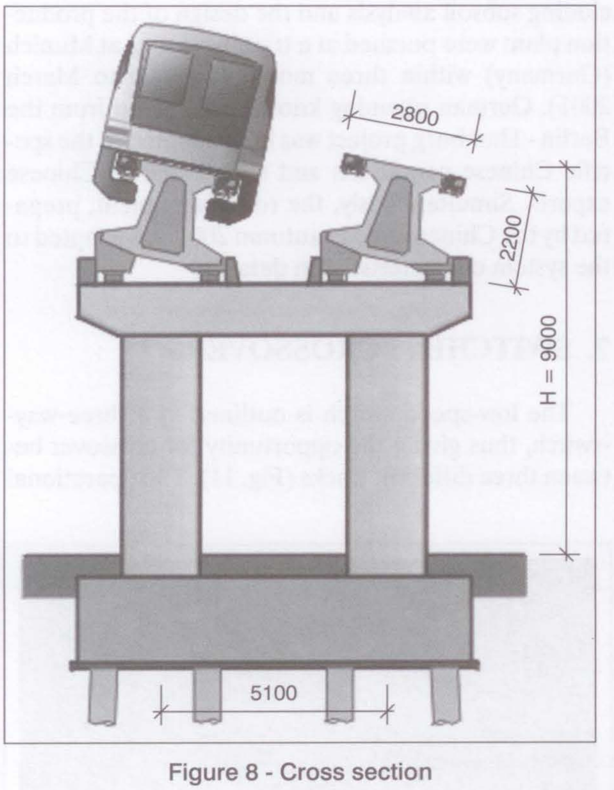

Figure 8 - Cross section

the guideway girders. After all, a guideway type was chosen for the Shanghai project with a span length of approx. 25.0 m and a height of 2.2 m (Fig. 7). The mounting weight of this type is about 165 t. If necessary two single-span girders may be coupled to one double-span girder by steel straps. This would reduce deformation due to temperature gradients between different girder surfaces. The modifications at the 2 x 12.4 m hybrid guideway girder consisted in the alternation of the double-span girder onto a single-span girder with approx. 12.4 m span length and simultaneous increase of the girder overall height of the solid cross-section of 1.0 to 1.4 m.

Since in Shanghai area the bearing capacity of the subsoil is extremely poor - strong ground shifts only in a depth of approx. 30 to 40 m, partly in 60 m - piles had to be rammed down in places all along the 30 km double track and the 3 km of maintenance track. Cross- and tie-beams on top of the columns bear the frames of the upper substructures strong enough to stand the high lateral forces. For that round prestressed concrete hollow piles with a general diameter of 600 mm were supplied in lengths of 12.0 m onto the construction site and rammed into the ground in a step-by-step way (Fig. 9). At the joints the piles were welded to each other by means of steel fittings.

5. PRODUCTION PLANT

In September 2000, months before the contracts were signed, the Chinese engineers began with the planning of a production plant for the manufacturing of the hybrid guideway girders. Starting from the plannings being present in Germany already for the manufacturing plant of the hybrid guideway girder for the project Berlin - Hamburg, the necessary adaptation occurred to the design dates and production capacities as well as the available plot geometry for a possible order of the production lines. The necessary

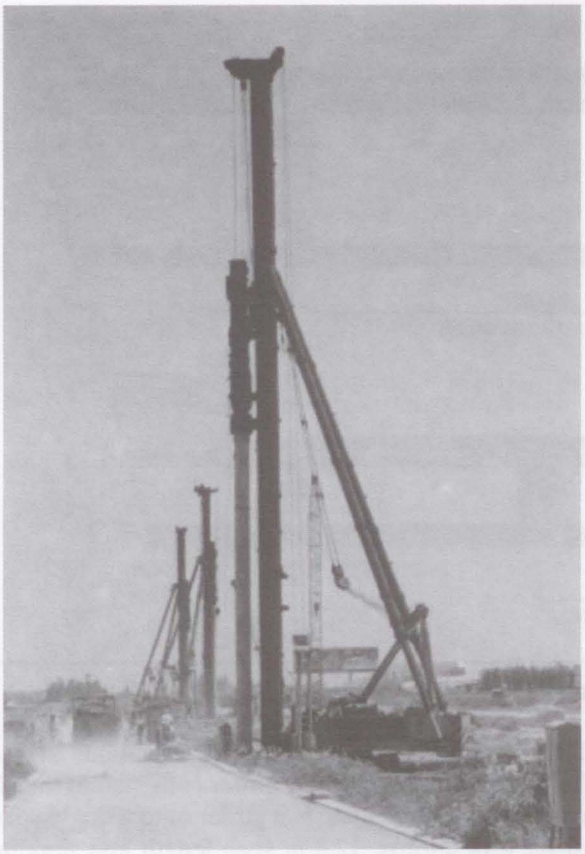

Figure 9 - Pile drivers

numbers per day which result from the total project requirements combined with the time schedule are the essential parameters for the design of the production plant. Due to the documents from the feasibility study a plot approx. 200 m wide and 2000 m long was found at the route, on which the production plant at track km 11.7 - 13.4 between the Long Yang Road Station and the Pudong Airport could be constructed.

The production hall measures about 100 x 200 m and is 12 - 14 m high (Fig. 10). That hall accommodates all trades, used for the production of the prestressed concrete box girders. In front of the hall the concrete plant was built up. The 2nd third of the ground is needed as a storage area for the hardening of the concreted girders. The large area is necessary so that most of the deformations from creeping and shrinking of prestressed concrete girders can fade away by storage over a period of 5 - 6 weeks. To assemble the prestressed concrete girders with the TRANSRAPID-specific construction elements a fully air-conditioned equipment hall was built. For the transportation of the guideway girders within the factory travel lifts (mobile cranes) with 400 t permissible load were produced in Italy. In order to realize the ambitious time schedule, for the production of the factory in spring 2001 only 4 months were available. Already with these first steps of realization it was learned how the Chinese manager wanted to handle this unprecedented multi-billion project in record time. Mandated with full authority, he seemingly disposes of infinite personnel and material. He follows the "Chinese arithmetic" by which time and capacity may replace each other.

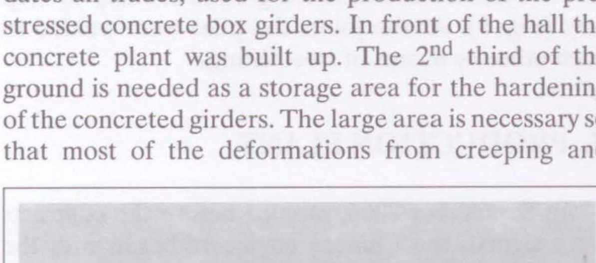

Figure 10 - Production plant

6. BASIC DETERMINATIONS

The consulting, training and primary outlines of the route planning, fine alignment, as well as of the construction of substructures and guideway girders including subsoil analysis and the design of the production plant were pursued at a training center at Munich (Germany) within three month (January to March 2001). German planning know-how, gained from the Berlin - Hamburg project was here adapted to the specific Chinese conditions and transferred to Chinese experts. Simultaneously, the route alignment, prepared by the Chinese side in autumn 2000 was adapted to the system characteristics in detail.

7. SWITCHES / CROSSOVERS

The low-speed switch is outlined as a three-way-switch, thus giving the opportunity for crossover between three different tracks (Fig. 11). The operational

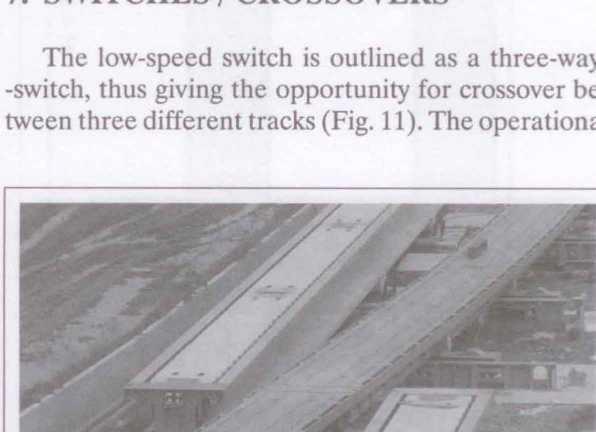

Figure 11 - Crossover

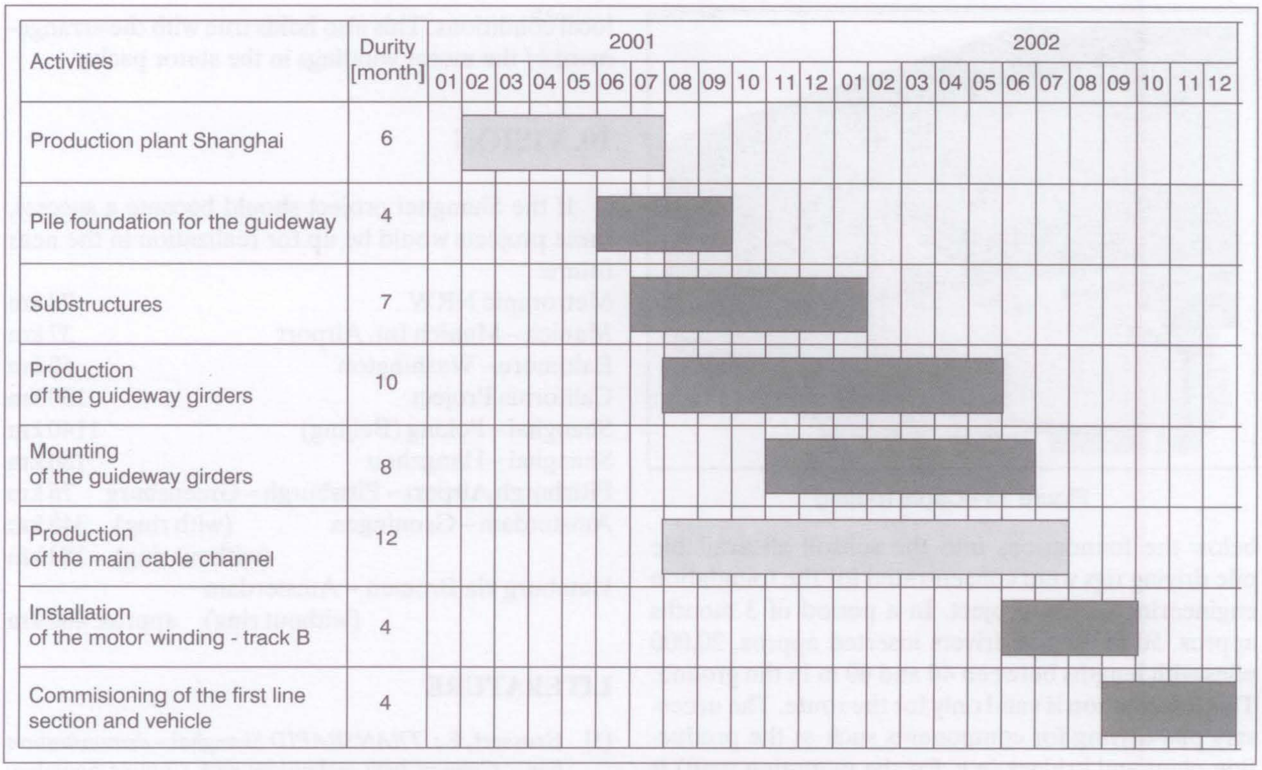

Figure 12 - Planned realization periods of main guideway components

speed for the straight position is 550 km/h, a maximum speed of 100 km/h is possible for bending position.

The supporting construction of the switch is a solid-webbed continuous steel box girder over eight spans with approx. 18.5 m and a total length of approx. 78.5 m. The box girder has vertical webs to reduce the lateral stiffness for bending the switch. In connection with the bottom plate a parallel-flanged box is supplied with cantilevers to assemble the operational components. The cantilevers with the functional components are integrated in the construction analogous to the steel guideway girder.

Shifting of the switch in horizontal direction is carried out directly above the substructures. During shifting, the box girder is bent from the stress-free straight position along the vertical axis. The bending girder is provided with the required form by deformations using switching drives at different locations. The route alignment of the switch in bending position is dependent on the maximum travel speed, the permissible acceleration and the permissible jerk. The moving measure of the box girder with a length of 78.5 m in horizontal projection conducts approx. 3.65 m in bending position.

In addition to the vehicles and the operation system the German consortium, consisting of Siemens, ThyssenKrupp and Transrapid International, delivered guideway-sided the stator packs with their windings, the power rails as well as the steel bending girders of the switches including the drives. The remaining guideway girders, substructures and foundations are made out by the Chinese side in complete responsibility on the basis of the preparation described in the precedent chapter.

Special cases are here the sections of the tracks, in which the steel bending girders of the switches are arranged, because these are also supplied by the German consortium. The interface between the Chinese designers and the German engineers was suited in this case on upper edge of the substructures below the switch constructions. A very intensive and closely interlocked coordination was here necessary, because the German evolutions for standard solutions had to be adapted onto the specific alignment boundary conditions and the surrounding in Shanghai. The processing of statically constructive concepts of the interface switch - substructures, considering the stability and the maglev specific requirements as well as the necessary cable routing, proved as most extremely extensive, because the information from the parallel Chinese plannings at the beginning of the project were available only very slow-moving in Germany.

8. DATES

For all project participants the VIP-run on track B on 01.01.2003 was committed already during the contract negotiations as an irrefutable date (Fig. 12). This means exorbitantly tough working discipline within the scope of this project. For example to drive the piles

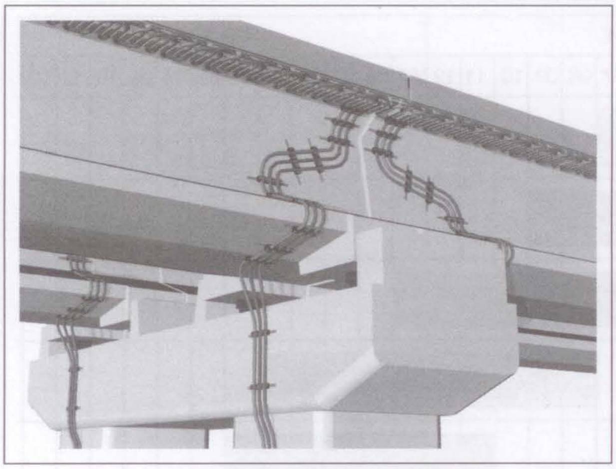

Figure 13 - Cable routing

below the foundations into the subsoil all available pile driving rigs were concentrated for the foundation engineering of this project. In a period of 3 months approx. 50 to 60 pile drivers inserted approx. 20,000 piles with lengths between 40 and 60 m in the ground. This information is valid only for the route. The necessary pile-driving for components such as the production plant and bridges (e.g. for the mounting road) is not included.

9. CABLE ROUTING – INTERFACE COORDINATION SYSTEM TECHNIQUE

The motor windings are supplied by German side and mounted by Chinese side. The German engineers are responsible for the super vision. The interface was adjusted in detail with the Chinese engineers. On basis of the Chinese design planning the overall cable routing at the guideway constructions was planned by the German side (Fig. 13) and coordinated with specific local conditions. This also holds true with the arrangement of the motor windings in the stator packs.

10. VISION

If the Shanghai project should become a success, these projects would be up for realization in the near future:

Metrorapid NRW	78 km
Munich – Munich Int. Airport	37 km
Baltimore – Washington	60 km
California Project	130 km
Shanghai – Peking (Beijing)	1140 km
Shanghai – Hangzhou	180 km
Pittsburgh Airport – Pittsburgh – Greensburg	76 km
Amsterdam – Groningen (with ring)	348 km
(without ring)	184 km
Hamburg via Bremen – Amsterdam (without ring)	approx. 480 km

LITERATURE

[1] **Grossert, E.**: *TRANSRAPID Shanghai – demonstration line - German high technology with Chinese boundary conditions*, 17th Int. Conference on magnetically levitated systems and linear drivers, Lausanne, Schweiz 2002

[2] **Grossert, E.**: *The Maglev system TRANSRAPID – an engineer construction of high quality*, 16th Int. Conference on magnetically levitated systems and linear drivers, Rio de Janeiro, Brazil 2000

[3] **Fechner, H., Grossert, E.**: *Die Magnetschnellbahn – ein Ingenieurbauwerk von hohem Rang*, Edition ETR - Eisenbahntechnische Rundschau 2001

[4] **Grossert, E.**: *Development and deployment of guideways for the TRANSRAPID*, TRB Transportation Research Board, Washington, USA Jan. 2000

[5] **Grossert, E.**: *TRANSRAPID Berlin – Hamburg, Fahrweg und Fertigungsstätten*, Bautechnik (1999) H. 2

Figure 14 - TRANSRAPID worldwide

[6] **Schwindt, G.**: *TRANSRAPID Guideway - Technical Standards,* 15th International Conference on Magnetically Levitated Systems, Yamanashi, Japan 1998

[7] **Grossert, E.**: *Guideways for TRANSRAPID - The guideway in its modular form*, 15th International Conference on Magnetically Levitated Systems, Yamanashi, Japan 1998

[8] **Fechner, H.**: *Der Weg ist das Ziel – Konzept ´97 der Transrapidstrecke Berlin - Schwerin - Hamburg*, Eisenbahntechnische Rundschau 46 (1997) H. 12, S. 773 - 780

[9] **Fechner, H.**: *Der TRANSRAPID – Umweltfreundliches Schweben zwischen Hamburg und Berlin*, Eisenbahntechnische Rundschau 45 (1996) H. 7/8, S. 471 - 478