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topic number 5

Route Alignment and Riding quality considerations of Guideways for the Maglev TRANSRAPID

Alignment - General

In the alignment of routes, engineers always have to take into consideration a range of criteria from different areas. Independent of the transportation system the following aspects must always be considered - with changing priorities -:

- Technical and operational capabilities of the respective transportation system
- Safety for construction and operation
- Environmental compatibility
- Traffic aspects, interconnection to the network
- Economy (guideway, buildings, operation, maintenance)
- Local / spatial situation, local constraint points
- Riding quality

The non-contact Maglev technology with the system-inherent flexibility of alignment parameters offers various possibilities for an economically and ecologically optimal route for speeds up to 500 km/h.

Like other railroad systems, the Maglev system is subject to geometrical limits resulting from constructional conditions (e.g. free rotation). These limits are maximum curvature values for horizontal and vertical curves, maximum cants and longitudinal inclinations, and maximum guideway torsion (changes in the cant).
The geometrical limits of the Maglev system allow great freedom in the route alignment and become relatively insignificant very quickly due to the great accelerating power of the system (> 1.0 m/s^2). Even at medium speeds the criterion of riding quality gain important influence on the selection and combination of alignment parameters. This criterion is the effect of accelerations and jerks (changes in acceleration) on the passenger. This is represented relative to the local guideway system vectorially by the direction components Longitudinal (x), Transverse (y), and Vertical (z).

Extract of Limiting Parameters (Guideline for Route Alignment of Maglev Guideways):

Max. Speed		V_{max}	500 km/h
Max. Cant		□	12 □
Max. Longitudinal Inclination		S	10 %
Max. Guideway Torsion		□□	0,10 □/m
Min. Radius – horizontal		R_H	350 m
Min. Radius – vertical		R_V	530 m
Max. Propulsion Acceleration		a_x	1,5 m/s^2
Max. Free Lateral Acceleration		a_y	1,5 m/s^2
Max. Lateral Jerk		$\mathring{a}_y$	0,5 (1,0*) m/s^3
Max. Vertical Acceleration	Crest	a_z	-0,6 m/s^2
	Sag	a_z	1,2 m/s^2
Max. Vertical Jerk		$\mathring{a}_z$	0,5 (1,0*) m/s^3

The increased jerks - marked "*" - represent maximum values for individual constraint points, the first listed limit applies to each of the other track sections. The maximum limit of lateral jerk for bendable switches in turnout direction is 2,0 m/s^3.

In addition to the high speed, the maximum transverse cant and the maximum longitudinal inclination are remarkable; in this case both limits have approximately double the value of those applied in traditional rail bound technology.
In comparison the higher cant enables a significantly higher speed at the same horizontal projection curvature and identical free lateral acceleration. The high-grade climbing ability enables a good alignment to the terrain features of the gradient. Combined with the possibility of elevating the guideway, the Maglev alignment can be designed flexibly even in the gradient.

With respect to this project, different limits for riding quality can be agreed with the operator and the authorising bodies, especially for accelerations and jerks; however, these limits must fall within the values set down in the directive for alignment.

Alignment Differences To Other Transportation Systems

Compared to alignment approaches of other transportation systems, some modifications have been developed for the Maglev system, which will be described below. These methods are appropriate and necessary due to the alignment possibilities as well as the big speed range.
This leads to the application of additional and more complex functions. But due to the comprehensive deployment of data progressing, which usual for today, these additional functions do not constitute a disadvantage. Traditional transportation systems, due to historical and technical conditions, understandably attempted to limit and simplify the necessary calculations.

The path of the Maglev will be defined separately in horizontal and upright projection first; then it will be computed and three-dimensionally superimposed. The so-called space curve has been created. Furthermore, taking into account the curvature ratios and the design speeds, an accompanying transverse cant band is developed. For the double track guideway "parallel" tracks are defined geometrically completely independently.

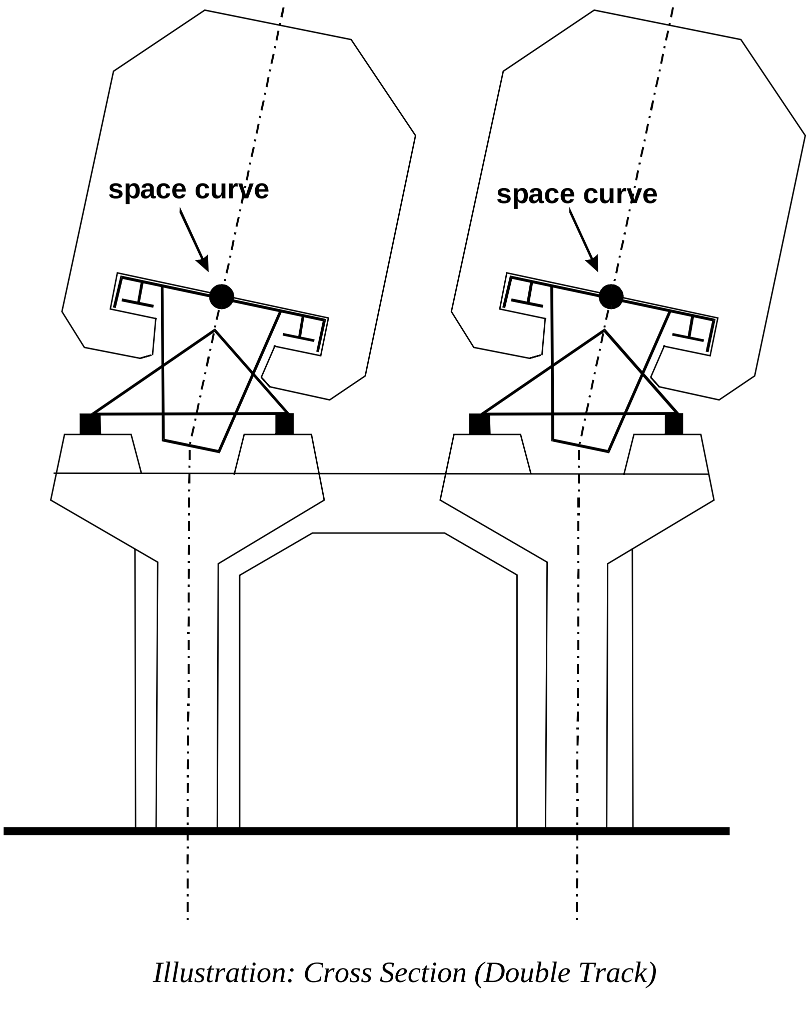

Illustration: Cross Section (Double Track)

Due to the pole pitch of the propulsion system it is necessary to consider the space three-dimensionally. The development of the true lengths is critical for the system, in contrast to the "shortened" lengths projected into the horizontal projection.
Due to the construction of the guideway (support separation and manufacturing), the construction requires the three-dimensional approach as well, especially since the differences in length between

three-dimensional route and horizontal projection can be significant due to the high climbing ability (longitudinal cant up to 10%).
For an exact evaluation of the riding quality the three-dimensional examination of the complex route alignment is necessary as well.

The gradient of the Maglev alignment is defined for each inclination change with geometrically precise circular arches. Normally in the construction of roads and railways only approximate solutions (parabolas) are used in the calculation of the gradient, because it is easier to illustrate and calculate these in their mathematical functions.
In order to avoid points of discontinuity in the gradient, clothoids are principally aligned as transition curves between the straight lines and the circular arches. This method ensures that, together with the curvature, the vertical acceleration caused by the curvature is also increased and decreased comfortably along the length of the transition curve. The length of these transition curves within the gradient is exclusively derived from the resulting vertical jerk. To put it simpler, the length is a function of the design speed and the vertical curvature. This integration of transition curves into the gradient primarily causes a significant improvement of riding quality.

Another critical difference to many other transportation systems is the choice of transition curves for the horizontal projection. The Maglev alignment between elements with varying curvatures (straight lines and circular arches) is realised exclusively with the help of sinusoids. The ramps in the transverse cant band are principally developed in the form of sinusoids, corresponding to the curvature change.
The continuous curvature band of the sinusoid is developed by linking a linear change in curvature (corresponding to the clothoid) with a sinusoid component whose period is equated to the length of the transition curve and whose amplitude eliminates the point of discontinuity from the beginning and the end of the transition curve. This ensures that lateral acceleration and lateral jerk are continuous functions (i.e. continuous and differentiable in every point) of the time and the travelled distance, in contrast to transition curves used previously (clothoids, cubic parabolas etc.).

The following are schematic views of the main differences in curvature graph, ramp development, and the development of lateral acceleration and lateral jerk between clothoids and sinusoids.

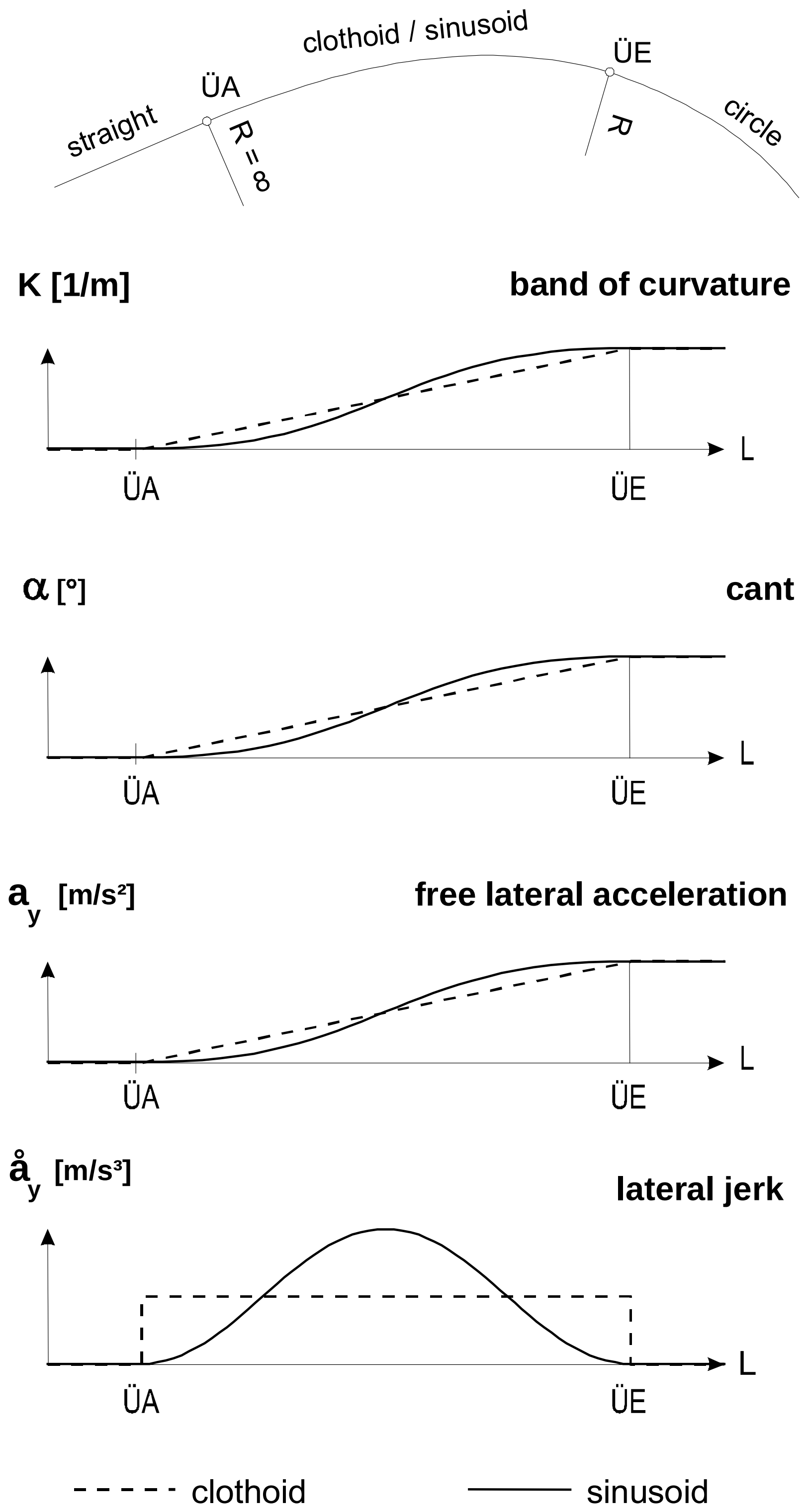

Illustration: Clothoid / Sinusoid

The sinusoid with its continuous progression of curvature, cant, acceleration, and jerk shows clear advantages for high-speed transportation systems in comparison with the clothoid:

- At the ends of the sinusoid ramp no "kinks" develop within the gradient of the guideway edges.
- The passenger will find the effects of riding quality - lateral acceleration and lateral jerk - at the same amplitudes significantly more comfortable through the "gentle" increase and decrease in sinusoids.

However, this improvement of riding quality results in that the sinusoid of a transition curve must have double the length of a clothoid under the same initial alignment conditions, if the resulting maximum lateral jerk is to be identical in both transition curves.

The alignment of reverse-curve is realised by one single reverse sinusoid each, because the riding quality become significantly more comfortable and smooth by this process in contrast to the use of two separate colliding sinusoids.

Another characteristic of the Maglev guideway is the so-called axle rotation around the space curve in the cant development.

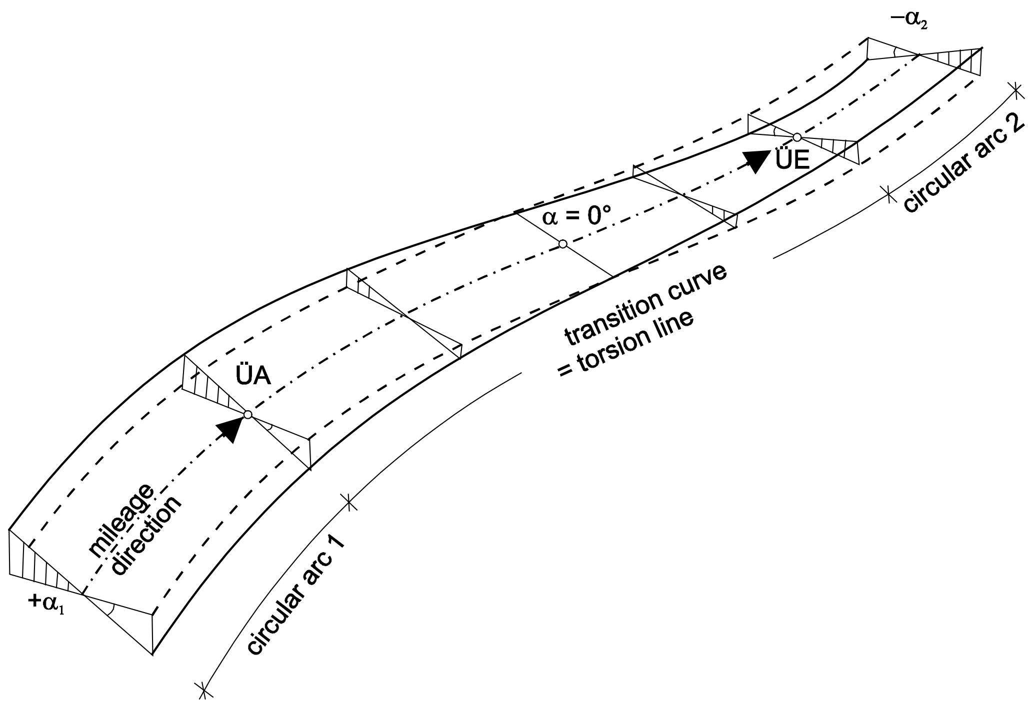

Illustration: Ramp

The space curve follows the alignment in horizontal and upright projection in the centre of the guideway; the edges of the guideway are rotated around this axle with the cant.

Differences in riding quality approach to other transportation systems

The effects of accelerations and jerks on the passenger determine the main parameters for the route alignment of the Maglev guideway. In addition to the imperative compliance with the limits, effort has to be made to achieve an alignment optimised in riding quality. This includes for example an almost balanced lateral acceleration in curves and a quality of acceleration and jerk that is as tempered as possible.

For the riding quality examination as well as for preliminary studies of riding quality during alignment works, the speed is a critical initial parameter. There is a very high interdependency, because the parameter speed influences the resulting accelerations to its second power, and the resulting jerks even to its third power.

This combination of functional dependency with the great range of speed as well as with the great accelerating power of the Maglev system has various results: not only are precise mathematical simulations necessary for a most exact evaluation of vehicle dynamics, but also there should be a correspondingly well approximated database of the (future) operational speed profiles.

The planning of operational speed profiles is itself dependent on the alignment as well, because here aspects of economy (energy consumption, travel times…) and possible local constraint points have to be considered, where the route alignment might require speed reductions and which will therefore have to be taken into account within the path of the guideway. This necessitates an interdisciplinary iterative process, which will result in the "fine tuning" of the alignment, and in the optimisation of the riding quality on the basis of "operational" speed profiles.

The alignment is examined and evaluated with the help of simulation programmes. These programmes evaluate all geometrical limits on the basis of horizontal and upright projections of the alignment, the transverse cant band and the speed profile (incl. acceleration and deceleration areas); they establish the riding quality values along the whole route and compare these values with the corresponding limits. The individual values are calculated taking into account the complex three-dimensional alignment, incl. "operational" speed profile; all possible deviations are recorded completely. The determined values are tabulated at desired intervals and are displayed in a graph (see following example).

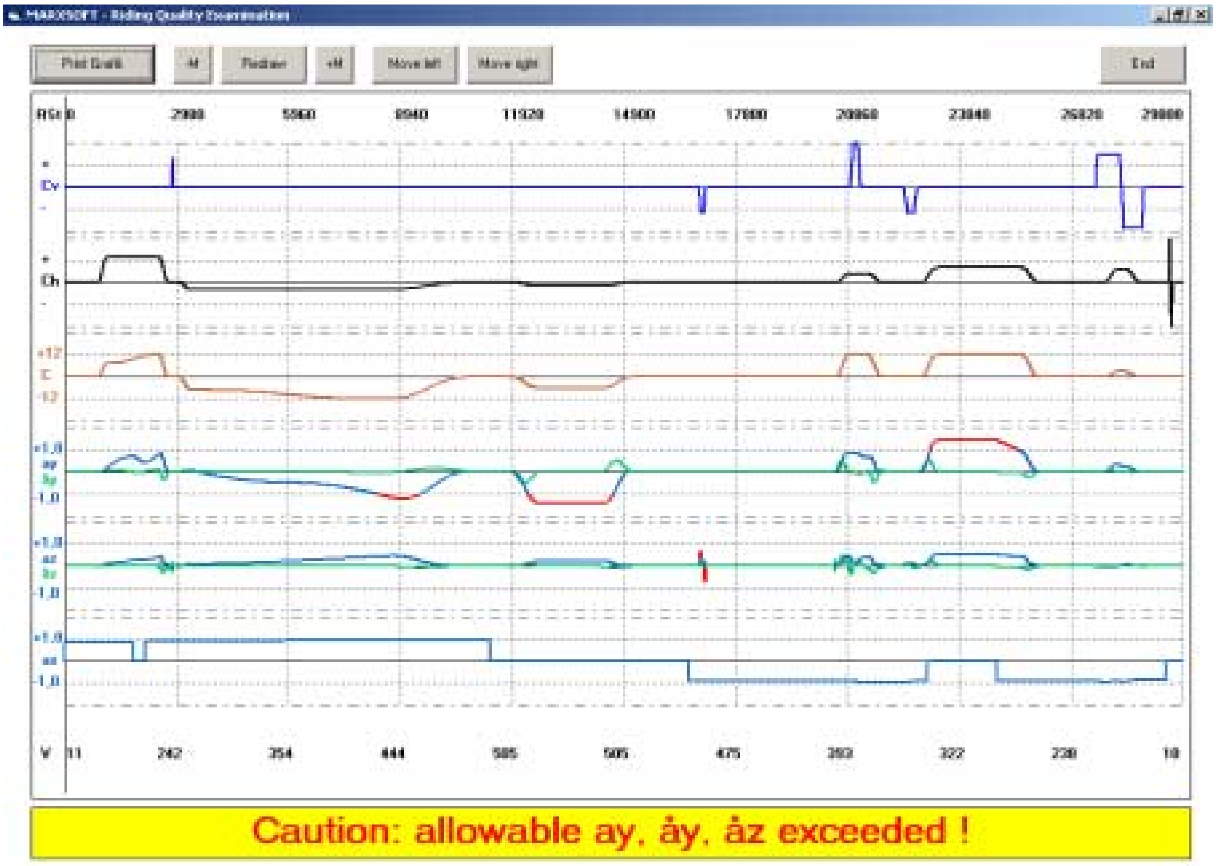

Illustration: Riding Quality Examination

This simulation not only takes into account the travel along the space curve, but also different seat positions in the cross section of the vehicle. This examination is appropriate because the superimposition of effects from space curve alignment and axle rotation (due to changes in cant) varies significantly depending on the seat position.

Because of this process one can run a simulation for a specific seat position. The resulting data enable test persons to travel the planned Maglev track in a simulator (e.g. flight simulator), and they can experience and evaluate it.

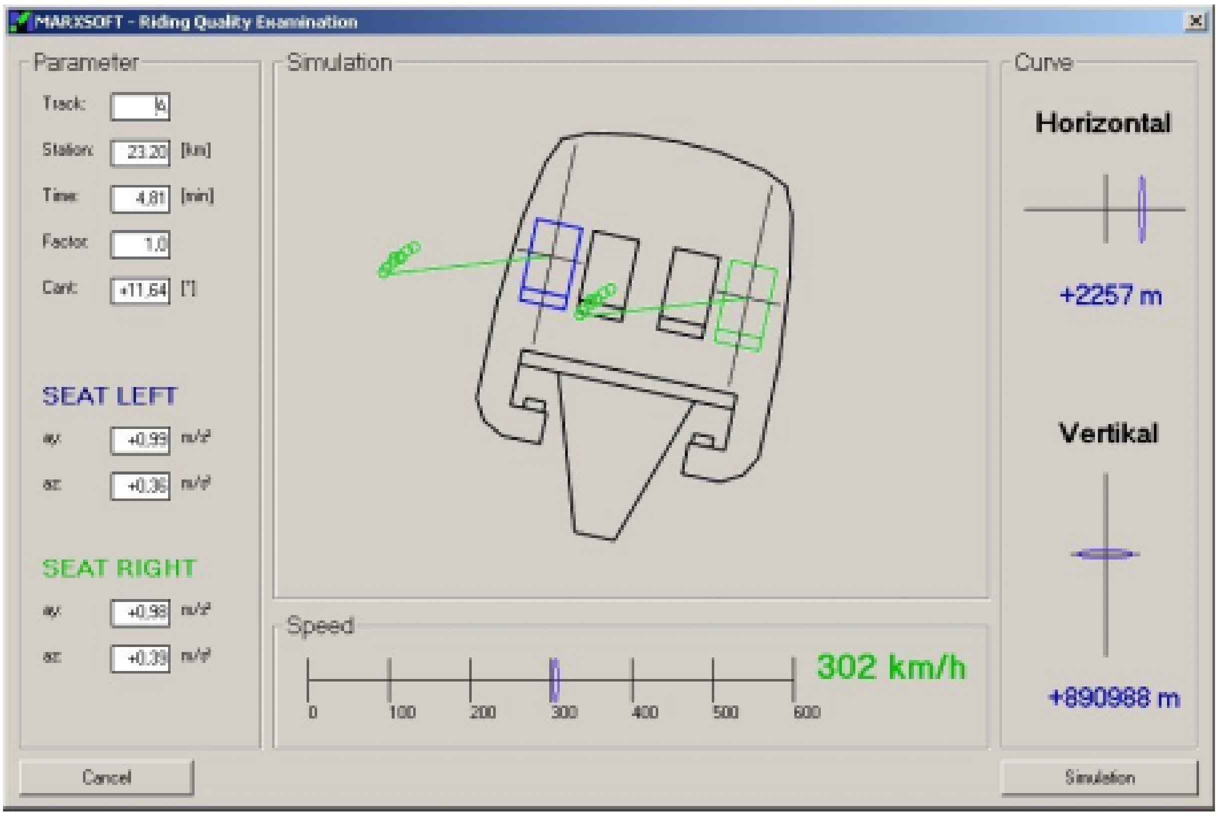

Illustration: Riding Quality Examination - Cross Section

Conclusions

In order to come to an optimal route for the guideway of the Maglev system, the particular parameters of riding quality have to be taken into account in addition to the economic and ecological conditions. Because the Maglev system is capable of relatively high speeds in comparison to other guided transportation systems, the application of sinusoids with their advantages in riding quality is an obvious element of alignment in horizontal projection. With regard to the riding quality the big advantage of the sinusoid - compared to other traditionally used transition curves - is the continuity in the lateral acceleration band and in the jerking curve. The alignment in upright projection is designed comfortably through the integration of clothoids between the straight-line gradients or descents respectively and the curves.

The alignment of the whole Maglev route is continuously screened for compliance with technical and riding quality limits using a realistic evaluation base resulting from riding quality simulations. This way all criteria of riding quality, taking into account the effects of deviations, can be established and evaluated completely during the precise three-dimensional examination of the space curve.

The aim of the simulations is not only the compliance with the limits of the system and the riding quality, but also specifically the riding quality optimization of the tracks in order to increase the already high riding quality, taking into consideration operational aspects like travel times, propulsion, and energy consumption.