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Translation

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Infrastructure for tilting trains

Infrastructure pour les trains à caisse inclinable
Infrastruktur für Neigezüge

UNION INTERNATIONALE DES CHEMINS DE FER
INTERNATIONALER EISENBAHNVERBAND
INTERNATIONAL UNION OF RAILWAYS

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Contents

Summary

Work was launched in early 1999 as part of a UIC study on reducing journey times on conventional lines. Following initial discussions, it was decided that the rules governing infrastructure for tilting trains would be harmonised on a documentary basis.

The project partners involved comprised not only railways already with tilting trains in operation but also ones which had plans to introduce tilting trains in the future.

Two significant results were produced: a list of essential parameters to be taken on board and the establishment of limit values. A list of parameters not affected by tilt was also drawn up.

For the sake of clarity, the leaflet also contains some explanations on basic technical subjects such as the impact of tilting trains on wheel/rail interaction. A table has been appended to the leaflet summarising all the rules adopted by the railway companies that were members of the working party. The table is therefore the starting point for the work carried out.

The most important considerations are the range of definitions (basic parameters such as maximum and minimum speeds, axle loads, track layout, cant deficiency to be applied, etc.), kinematics, track equipment and track geometrical quality, interface parameters track/train, etc.

Maintenance-related topics were not covered by the work. Some railways have advocated carrying out studies with a view to determining speed increases that could be achieved by running tilting vehicles on high-speed lines.

1 - General

Body tilting is a design technique for railway passenger vehicles. It enables the bodies of coaches to be tilted about a longitudinal axis thus limiting the lateral acceleration of the vehicle body and its effect on the perceived comfort of the passenger. This makes it possible for vehicles with tilting bodies to negotiate curves at higher speeds than conventional coaches, without adversely affecting passenger comfort.

The objective of this Leaflet is to pool knowledge concerning the conditions recognised as necessary in order for the track to be used to carry tilting trains on conventional lines.

This definition reflects the needs expressed by the UIC railways in the course of the joint work on the state of the art of tilting train technology.

In the interests of efficiency, this Leaflet only covers measures relating to use of tilt technology and not those relating to the increase in speed. Nor does it cover, at least not in the initial stage, the effect of tilt on signalling (control-command). Work on this Leaflet has been carried out in close coordination with the work on vehicle type approval carried out to adapt *UIC Leaflet 518* to include tilting body stock (*UIC Leaflet 518-1*).

This Leaflet relates to the track design parameters for operation of tilting trains. The impact of this type of traffic on track maintenance is not addressed. Railways operating tilting trains may adapt the design parameters in the light of any acceptable additional maintenance.

2 - Basic parameters used

2.1 - Revenue speeds of tilting trains

For the most part the railways operate tilting trains at speeds of between 70 km/h and 230 km/h. However, there is no objection to considering a starting speed as low as 50 km/h.

This lower limit of 70 km/h is dictated by the tilt control systems. In fact these systems do not trigger the body tilt mechanism at lower speeds chiefly because, when negotiating switches onto a turnout, the tilt system accentuates movement in the vehicle body. What is more, there does not appear to be a great deal of commercial value to be gained from using this technology at low speeds.

The upper limit (230 km/h) corresponds to the speed normally reached on lines carrying conventional trains with cant deficiencies of 150 mm.

For information, two revenue speed ranges may be considered for the different types of tilting trains:

- one from 70 to 160 km/h for regional trains requiring tilting stock suitable for service on very sinuous lines;
- the other from 70 to 230 km/h for national trains requiring rolling stock suitable for use on sinuous lines but also on lines with alignment designed for high speeds.

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2.2 - Maximum axleloads

Tilting trains operate with higher cant deficiencies than those required for conventional trains and normally exert heavier loads on the track. It is therefore advisable for axleloads to be lower and for the suspension to be of high quality.

The restriction on axleloads has a significant effect on whether the limits of the Y and Q forces relating to track fatigue are adhered to, and to a lesser degree on the slewing (lateral displacement) of the track.

The track slewing limit is governed by Prud'homme's formula:

$$\Sigma Y = \alpha\ (10 + P / 3),$$

expressed in kN, the constant term of which corresponds to the strength of the unloaded track. The lighter the axleload, the greater the relative effect of this term.

It is recommended not to exceed an axle load of 180 KN.

Furthermore, if the value of the Y and Q forces is associated with the axleload, the dynamic component of these forces will depend on the geometrical quality of the track and on the quality of the suspension systems which filter the track geometry defects to a greater or lesser degree. The quality of the suspension also has an effect on the transverse force Y and consequently also on whether the Prud'homme and Y / Q criteria are satisfied.

In addition, two types of track system may be distinguished:

1. the normal track system, as used in the Prud'homme studies;

2. the "modern" track system (heavy track), a feature of which is the higher fatigue strength and higher resistance to lateral displacement of the track.

Nonetheless, a distinction must be made between rolling stock type approval conditions as specified in *UIC Leaflet 518*, which defines a given requirement for rolling stock, and actual operating conditions. Consequently, it is logical to consider that the best interests of infrastructure managers lie in reducing the axleload as much as possible. Such a reduction in axleload, however, raises difficulties in the design of vehicles.

The questions raised in this section might well be the subject of future and deeper investigation.

3 - Line alignment

There are no or practically no special line alignment conditions to be met in respect of the ride quality of tilting trains; the key parameters for operation of conventional trains generally apply similarly to tilting train operation.

On conventional lines the current practice is not to modify the line alignment if it can be avoided, so as not to unduly increase the cost of a project.

However, certain line alignment parameters may prove to be sensitive, depending in particular on the tilt control system used.

Ultimately, the future CEN specifications and the criteria set by certain railways (Banverket, REFER, Railtrack, etc.) for construction of new lines or up-grading of conventional infrastructure, may include certain recommendations to take account of tilting train operation to a greater extent.

3.1 - Minimum curve radius (R)

As far as the ability of tilting trains to negotiate small-radius curves on existing track is concerned, the minimum permissible radii for tilting trains are as a rule the same as those applicable to standard trains. Nonetheless, if tilting trains are to negotiate small-radius curves, it may be necessary to lower cant deficiency somewhat (see point 4.1 - page 7).

3.2 - Transition curves

Transition curves affect the way in which tilting trains enter and exit from curves, particularly the ability of the tilt mechanism to react effectively to the change in curvature. Both active and the passive tilt systems take some time for the body to adapt its angle of tilt to the curve radius and it is for this reason that curves must include transition sections. The length and form of curvature of these transition sections is an important aspect of the line alignment.

3.2.1 - Length of transition sections

The length of the transition sections should be such that the tilt system is able to operate correctly depending on the train speed. Observing the rates of change of cant dD/dt, as defined in point 4.2 - page 8, is sufficient.

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3.2.2 - Proportionality between curve and cant

The transition curves must coincide with the cant gradients. If they do not, then specific running tests are recommended to determine to what extent the maximum permissible cant deficiency may need to be reduced.

3.2.3 - Distance between successive transition sections

The distance between successive transition sections, however, is not a decisive parameter. Even special cases are acceptable where there is no straight section between two successive transition curves (or there is an inflection point or there are juxtaposed curves running in the same direction). It is considered that, for reasons of continuity of the cant gradient, it is better to place an inflection point between two transition curves than to have a short straight section between two transition curves.

3.3 - Cant (D)

3.3.1 - Minimum cant (D)

The minimum cant set depends solely on the curve detection system installed on the vehicle. If the change in cant is small, there is a danger that if the detection mechanism on the train is based on measurement of the cant, it will not be able to detect the curve. In such cases, the cant specified should not fall below a certain threshold.

This minimum value below which the tilting of the vehicle can no longer be guaranteed, is of the order of 20 mm.

R ### 3.3.2 - Minimum change in cant between successive curves

For the same reasons this limit also applies between successive curves running in the same direction. If the cant variation (there is always a ratio between the curvature and the cant) between two successive curves does not exceed this limit, the speed calculation needs to be made with respect to the most stringent value of the combination of radius and cant.

3.3.3 - Maximum cant (D)

There are no specifications peculiar to the tilting body technique for limiting the maximum cant.

Consequently, the limiting values for the maximum cant are those currently fixed for operation of conventional trains.

4 - Kinematics

This chapter concerns the kinematics of ride of tilting trains, i.e. the parameters connected with the profile of the curves in combination with the speed of trains.

Of these parameters, it is cant deficiency which essentially increases the level of the accelerations exerted on tilting coaches, and consequently also the loads transmitted between the coaches and the track, which affects the safety of tilting trains and the track fatigue.

4.1 - Cant deficiency at the level of the track (I)

4.1.1 - Maximum deficiency (I)

When negotiating a curve a vehicle is subjected to a centrifugal quasi-static acceleration which generates a quasi-static lateral force on the track. In the plane of the track this acceleration is a direct function of the cant deficiency in the curve.

This quasi-static lateral force becomes significant with the cant deficiencies used for tilting trains. And it increases still more when it is considered that the effect of the (quasi-static) centrifugal force on the axles of a bogie is not generally distributed symmetrically over the two axles, but rather asymmetrically depending on the radius of the curve being negotiated (it may be observed that if radially adjustable wheelsets or independent wheels are used, this asymmetry diminishes).

There is also the fact that the dynamic forces caused by track geometry defects increase with the speed, a speed which is increased on account of a higher permissible cant deficiency.

But in addition it should also be considered that this high cant deficiency reduces lateral play between the bogies and the vehicle body (absorption of free play and crushing of the elastic bearers) thus resulting in greater sensitivity of the vehicle to track irregularities.

Operation of a line at tilting train speeds (speeds commensurate with a cant deficiency greater than that permitted for operation of conventional trains) thus means, in principle, the forces exerted by tilting trains on infrastructure are higher.

In view of the physical constraints coming from track fatigue, safety and passenger comfort requirements, tilting trains should:

- have lighter axleloads than conventional trains, so as to reduce the quasi-static part of the loads exerted on the track: forces Q, Y and ΣY affecting the level of track fatigue and

- be equipped with sophisticated suspension systems to reduce sensitivity to track geometrical irregularities despite the higher permissible speeds, thus reducing the dynamic part of the forces Q, Y and ΣY as well as the substance of the parameter Y/Q.

These systems generally consist either in a reduction of the non-suspended and partially suspended masses acting directly on the track, or in the use of active lateral suspension systems which avoid the transverse impacts of the body of the train against the bogie, so that the Y forces finally exerted on the track are reduced.

The maximum value most often adopted in operating without giving rise to any special problems, or envisaged in studies relating to increasing speed through use of the tilting technique, is 275 mm on standard gauge tracks, i.e. 1,8 m/s^2 non-compensated acceleration, and this may therefore be used as a reference.

However, since 28 May 2000, DB AG have been using up to 300 mm cant deficiency (non-compensated acceleration of 2 m/s^2 with standard track) in revenue service. There are also other European railway companies which have decided upon this value for revenue operation for future projects.

For passive body tilting systems, because of the different characteristics of the vehicles, a non-compensated acceleration of 1,2 m/s^2 is normally obtained in revenue operating practice.

4.1.2 - Limitation of deficiency (I) as a function of the curve radius (R)

In the case of very small radius curves, the constraint of not exceeding the level of the forces exerted on the track may limit the maximum cant deficiency which can be used. In fact in such small radius curves, the leading wheelset undergoes a significant quasi-static transverse force and is also sensitive to alignment defects.

For curves of 250 to 400 m radius, it may be necessary to limit cant deficiency in the light of the results of type approval tests for a train.

4.1.3 - Restrictions on deficiency (I) for special features in the track

Depending on the characteristics of certain special features in the track, such as certain switch and crossing work in curves, bridges carrying direct-laid ballastless track, certain level crossings, certain sections of line exposed to very strong cross winds, etc., it may prove necessary to restrict the permissible cant deficiency.

Rules in respect of these restrictions cannot be formulated beforehand since they will be dictated by the design of the special features; definition of such a frame of reference can only be left to the initiative of railway companies.

R 4.2 - Rate of change of cant dD/dt

The rate of change of cant affects the possibility of tilting trains inclining the body correctly. The values adopted for conventional trains need to be increased according to the increase in speed. The maximum value of dD/dt applying to conventional trains is 60 mm/s (limit set by the CEN draft). This limit can be increased by 25% (i.e. up to 75 mm/s) for tilting trains. Specific tests are recommended in the case where the 75 mm/s value would be exceeded.

4.3 - Rate of change of cant deficiency dI/dt

The change of cant deficiency in a vehicle is a comfort problem for passengers, who experience an uncomfortable jerk.

However, the residual cant deficiencies in the vehicle body are less than those obtained with conventional stock, and consequently the dI/dt parameter is not significant. On the other hand, the tilt control system creates transient states at the entry to curves, which may give rise to even more pronounced jerks.

There is therefore no point in defining a dI/dt (quasi-static) criterion for tilting stock.

5 - Track

5.1 - Track equipment

The track equipment to be used as a reference for tilting body trains is the same as that used for conventional trains.

The characteristics of heavy track, which can accept higher fatigue and slew limits, might be defined as follows:

Profile of rail	:	UIC 60, UIC 54
Grade of steel	:	900A (recommended)
Type of sleepers	:	concrete
Sleeper spacing	:	60 cm
Type of fastening	:	resilient direct or indirect
Continuous welded rail	:	recommended
Type and section of ballast	:	very high quality and sufficient ballast profile

In the above track conditions, Prud'homme's formula allows a reserve margin which could be utilised by constructing a new formula which takes account of the actual limit of lateral displacement.

5.2 - Quality of track geometry

For most railways, the quality of the track geometry is not a decisive parameter for the cant deficiency adopted on the line. On the other hand there are frames of reference for quality of track geometry which have been established as a function of the speed ranges adopted for the line.

The introduction of tilting stock on a given line means an increase in the line speed and therefore, in certain cases, a change in the quality of track geometry relative to the new speed ranges.

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6 - Speed increase tests

Until now speed increase tests have been found necessary in order to confirm the tilting speeds practised in revenue services.

These tests are recommended and particularly on lines or sections of line where the composition of the track equipment, the line alignment, the kinematics (minimum R, dD/dt, etc.) do not correspond to the reference or recommended values.

They are also recommended in cases where the cant deficiency in revenue operation is greater than 275 mm.

The tests should be undertaken using a suitably instrumented tilting train and their purpose should be to determine whether the safety parameters (lateral displacement of the track, derailment, overturn) developed (or to be developed) by *UIC Leaflet 518* are satisfied.

Experience gained in this area may make it possible to simplify these tests, using less complex measuring methods, or even to dispense with any test runs in cases where the parameters considered critical remain within acceptable limits.

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7 - Other areas

7.1 - Monitoring of speed. Protection against excess speed

Where speed control systems have been installed, either in the cab or by means of devices connected to the track, the control threshold should be linked to the risk of overturn of the vehicle.

7.2 - Sign boards

Where a rate of speed is signed on the track, the introduction of tilting trains may call for installation of special boards.

7.3 - Interaction between pantograph and overhead line

Smooth interaction between the pantograph and overhead line - on account of the movements of the body of the train - should be achieved by using special devices to adapt the pantograph to the tilt of the body dynamically or by direct connection of the pantograph to the bogie.

7.4 - Equivalent conicity

No special arrangements need be made when tilting train technology is used, but certain measures need to be taken on account of the higher speeds applied.

7.5 - Clearance gauge

Checks shall be made with respect to the clearance gauge for the body tilting equipment in normal operating conditions and in failure situations.

7.6 - Pressure impacts in tunnels and in the open

No special arrangements need be made when tilting train technology is used, but certain measures need to be taken on account of the higher speeds applied.

7.7 - Protection of people on station platforms

No special arrangements need be made when tilting train technology is used, but certain measures need to be taken on account of the higher speeds applied.

7.8 - Power supply

No special arrangements need be made when tilting train technology is used, but certain measures need to be taken on account of the higher speeds applied.

The power required for the body tilt may be taken into account where necessary.

8 - Information for the purpose of extending *UIC Leaflet 518* to cover tilting trains (*UIC Leaflet 518-1*)

As regards the extension of *UIC Leaflet 518* to cover tilting trains, the following reference parameters are to be provided:

The track equipment, the line alignment and the geometrical quality of the track required for operating tilting trains are the same as those already fixed for conventional vehicles and, in particular, the frame of reference described in *UIC Leaflet 518* which can be used as a basis for choosing the tracks on which to carry out type approval tests on vehicles also applies in the same way to traffic on lines with standard types of track.

The reference cant deficiency chosen should be 275 or 300 mm.

However, if certain limit values are not adhered to by a vehicle in one or more test sections, additional analysis should be undertaken with a view to determining:

1. the reduced permissible cant deficiency I_{red} throughout the whole range of this category of radius;

2. the radius ranges for which the cant deficiency I_{adm} is practicable.

It should be possible to set a higher lateral displacement limit for operation on heavier tracks.

However, studies would need to be carried out first in order to ascertain the safety margin provided with such tracks. These studies would necessarily be extensive because they would have to take account of all heavy concrete-sleepered tracks in place today, as well as slab tracks.

Furthermore, some railways advocate that studies be carried out to determine the increase in speed which might be achieved by running tilting vehicles on high-speed lines.

Appendix A - Summary table

Infrastructure for tilt-bodied trains

To be validated by each railway

			BV	CD	DB AG	FS	HZ	JBV	RAIL-TRACK	REFER	RENFE	SBB	SNCB	SNCF	VR	ZSR
PARAMETERS	Speed	Minimum speed (km/h)	80	70	70	70	70	70		65	70			70	70	70
		Maximum speed (km/h)	200	160	160 (230)	200	160	160		220	220	160	160	220	220	160
	Axle load	(kN)	180	160	< 160			180		145				≤160 kN	≤146 kN	
TRACK ALIGNMENT	Cant	Minimum D (mm)		30	20		20			30		20			20	30
		Maximum D (mm)	150	150			160	150		180/200	160		150		150	
		Difference in D for adjacent curves (mm)		30						No						30
	Curve radius	Minimum R (m)	180					180		250	250				180	
	Transition curve	Transition curve present	Yes	Yes				Yes		Yes			Yes		Yes	Obligat.
		Transition curve coincide with cant transition	Yes	Yes				Yes		Yes			Yes		Yes	
		Distance between adjacent transitions (m; V=km/h)	0,25 V	0 or 0,2 V				0,25 V		0					0	
		Others														
		Shape	Clothoid					Clothoid		Clothoid	Clothoid					
KINEMATICS	Cant deficiency	Maximum approved value of I (mm)	245	270	300 (260)	275	275 (290)	280	265 (300)	293/319 (diff. gauge)	245/282 (diff. gauge)	275		260	275 (diff. gauge)	270
		Limitation of I as function of radius R (mm)	No	240 (300 m)	No	No	No	No	110 (400 m)	No	No	240 (350 m)	No	< 450 m	Yes	No
		Limitation of I for special points:														
		ballastless bridges (mm)	No	130	150			180	Yes					Yes	106	130
		switches in curves (mm)	150	110	150			180	Yes	150	Yes	Yes			106	
		special types of switch (mm)		130		for diamond crossing with slips Vmax=175 km/h		180	110/150			Yes			106	110/130
		expansion joints (mm)		130					Yes			Yes				130
		rigid type level crossings (mm)	No	130	150			180	Yes							130
		trackbed							Yes							
		others		130					Yes			Yes		Bridge fatigue		Yes
	Rate of change in cant, dD/dt	mm/s	70	46 70 (Bloss)				75	75 (95 exc.)	61 (2°/s)	50		60		35	
	Rate of change in cant deficiency, dI/dt	mm/s	79	116				140	110 (150 exc.)	90 (124 exc.)	75		Yes			
	Ratio of cant deficiency / cant, I/D			≤3 (3,5 exc.)												≤3 (3,5 exc.)
TRACK	Track equipment	Rail type and profile	BV50/UIC60	S49/UIC60		Yes	S49/UIC60	S54/UIC60		UIC54/60	UIC54/60	UIC54/60	50T/UIC60	Yes	UIC54/60	
		Steel grade	900A	900A	Yes		700-900	900B		900A/1100A	900A				780-930	
		Type of sleepers	concrete	concrete/ wooden	Yes	Yes	concrete/ wooden	concrete		wooden/ concrete	concrete		wooden/ concrete	Yes	concrete	
		Sleeper spacing	650 mm	600 mm	special if R<850m			600 mm		600 mm	600 mm		600 mm	Yes	610 mm	
		Type of fastenings	Resilient	Resilient		Yes	Resilient	Pandrol		Resilient	Resilient				Resilient	
		Continuous welded rail	Yes	Yes				Yes		Yes	Yes				Yes	
		Ballast type and cross-section	Good quality stone (M1) (32-64 mm)	Crushed stone			Crushed stone	Good quality stone (25-63 mm)		Yes						
		Others	Rail at 1/30					Rail at 1/20		Rail at 1/20						
	Track geometry quality		Yes (Class KD)	-				Yes	Enhanced at special pts.					Yes		

			BV	CD	DB AG	FS	HZ	JBV	RAIL-TRACK	REFER	RENFE	SBB	SNCB	SNCF	VR	ZSR
TYPE APPROVAL	Tests according to *UIC Leaflet 518*		Yes	Yes		Yes		Yes	Yes	Yes	Yes	Yes		Yes	Yes	
OTHER POINTS	Safety criteria (track displacement, derailment, overturning, etc.)		Yes					Yes								
	In-cab speed control								Yes						Yes	
	Protection against excess speed		Yes (ATC)					Yes	21% as from 20 mph	Yes CONVEL				Yes	ATC	
	Signalling													Yes	Yes	
	Pantograph-OHL interaction							Yes				Yes			Yes	
	Overhead lines (OHL)															
	Equivalent conicity															
	Gauge		Check					Check		Check				Check		
	Pressure impacts in tunnels and on open track		Check					Check							Yes	
	Protection of people on station platforms		Indicate on station platform					Partial							Yes	
	Power supply															
	Other													TGV braking		
OTHERS																

Glossary

Jerk	Acceleration fluctuation in time

List of abbreviations

D	cant
I	cant deficiency at track level
P	axleload
Q	vertical force
R	curve radius
Y	transverse force

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