Tilting body railway vehicles,
Parameters definition,
Balanced score cards

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NEW APPROACH TO PARAMETERS DEFINITION OF TILTING BODY RAILWAY VEHICLES

Increasing speed of railway passenger transport is a task for all railways. There are two basic possibilities for speed increasing – by new high speed tracks construction with maximum speed over 250 km/h, or by utilization of existing tracks where tilting body vehicles can be operated. Slovakia is not an exception in these efforts. Analysis of theoretically attainable running times on selected ŽSR railway line (Bratislava – Žilina – Košice) by computer simulation program are presented together with discussion on actual situation on already modernized corridor. Parameter areas affecting selection of suitable tilting body railway vehicle and proposed methodology (Balanced Score Card) for determination of optimum parameters of new vehicles for ŽSR are presented. The methodology evaluates the parameters in a balanced way and in mutual relationships.

NOWE PODEJŚCIE DO DEFINICJI PARAMETRÓW POJAZDÓW KOLEJOWYCH Z WYCHYLNYMI PUDŁAMI

Wzrost prędkości pociągów pasażerskich jest obecnie zadaniem realizowanym przez większość zarządów kolejowych. Obecnie można mówić o dwóch metodach zwiększenia prędkości pociągów – budowa nowych linii dedykowanych do pociągów dużych prędkości powyżej 250 km/h oraz wykorzystanie istniejących linii na których operują pociągi z wychylnymi pudłami. Słowacja nie stanowi w tym względzie wyjątku. W referacie przedstawiono symulacje komputerowe teoretycznych możliwości pociągów z wychylnymi pudłami na modernizowanej linii Bratysława – Żylina – Koszyce wespół z dyskusją na temat obecnie modernizowanego korytarza. Zaprezentowano nową metodologię optymalizacji parametrów nowych pojazdów szynowych dla kolei słowackich.

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1. INTRODUCTION

One of the leading trends in the railway transport is increase of running speed. This is true in particular for passenger transport, yet in smaller extent also in cargo transport. On the top are systems of high speed trains where maximum speed is over 250 km/h.

Basically, there are two ways how to increase running speed.

One way is construction of special high speed tracks with curves with large radii corresponding to high speed of railway vehicles.

The second way is utilization the existing tracks, certainly with enhancement of their technical conditions, and use of railway vehicles with tilting bodies which allow faster run in curves by tilting body inward the curve and thus reducing effects of centrifugal forces on passengers. However, thorough analysis for proposal of required parameters of new vehicles has to be done.

2. RAILWAY VEHICLES WITH TILTING BODIES

There are two basic principles of body tilting:

- natural tilting (fig. 1),
- forced tilting (fig. 2).

Natural body tilting is based on a principle of body support by air springs on the bogie above its centre of gravity. This support enables body tilt inwards the curve by action of centrifugal force and by this partially compensate effects of centrifugal force on passengers. The best known representative of trains with natural body tilting is Spanish RENFE train-set called Talgo.

Into the group of vehicles with forced body tilting belong e.g. Italian train units FS Pendolino, its derivate German DB - VT 610, or on partly different principle designed Swedish train SJ - X 2000 [1]. Many other systems exists in the world (Japanese, using body supported on rollers and electric actuators; active secondary air suspension raising outer and lowering inner side of body during curve run, etc.)

Forced body tilting of railway vehicle is based on principle of tilting vehicle body by action of hydraulic, pneumatic or electrical actuators. In figure 2 is a vehicle body supported on transverse beam in a bogie and tilted by hydraulic cylinders of newer system Pendolino (ETR 460, ETR 470, etc.). Original solution (ETR 401, ETR 450) was realized by means of two long vertical hydraulic cylinders on each bogie which tilt body in its top part while bottom frame of body was hanged on fully suspended transverse beam.

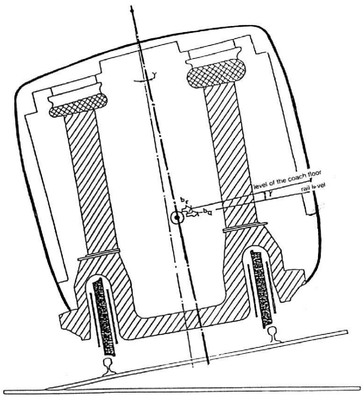

Fig.1.Natural body tilting of railway vehicle (Talgo Pendular)

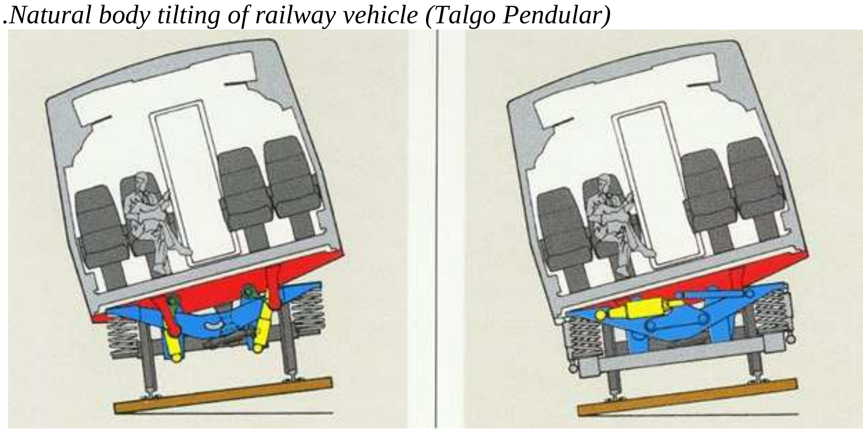

Fig.2 Forced body tilting of railway vehicle (Pendolino)

2.1 Forces acting on railway vehicle running in curve

When running in curve, centrifugal transversal force is acting on vehicle. Corresponding transversal (centrifugal) acceleration poses several undesirable effects:

- discomfort for passengers,
- possible derailment of vehicle,
- transversal effects on track.

To minimize above given undesirable effects it is possible:

- use the maximum possible curve radius,
- decrease speed in curve,
- create track superelevation to compensate the transversal acceleration.

Superelevation (rail cant) is placing outer rail in a curve higher against the inner rail by value of "p" (mm) (fig. 3).

During run in curve, effects acting on a vehicle are shown in figure 3 [1].

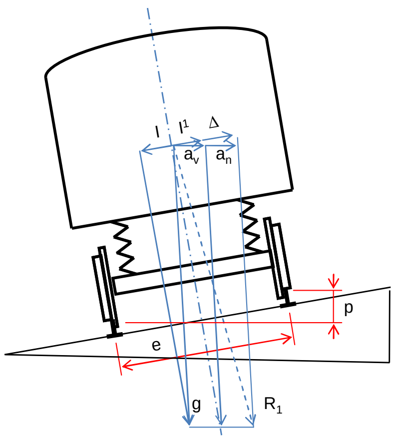

Fig.3 Effects acting on railway vehicle during running in curve

Effects acting on a tilting body vehicle during run in curve are presented in figure 4 [1]. Tilt of body relative to bogie frame can be observed there.

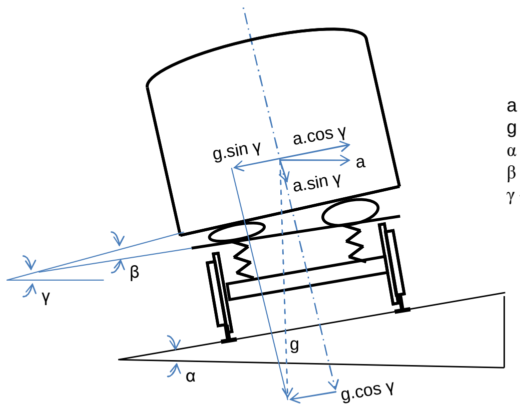

Fig.4 Effects acting on tilting body vehicle during running in curve

Overall tilt of body during run in a curve is a sum of superelevation (rail cant) of outer rail and fictive superelevation resulting from body tilt [2].

If we consider curves with uniform superelevation p = 150 mm and cant deficiency of 70 mm, or 100 mm, we can make diagram of relation of maximum speed in curve to curve diameter for a vehicle with tilting body and for conventional vehicle (figure 5). Horizontal axis in the diagram starts by value of 100 m of curve radius.

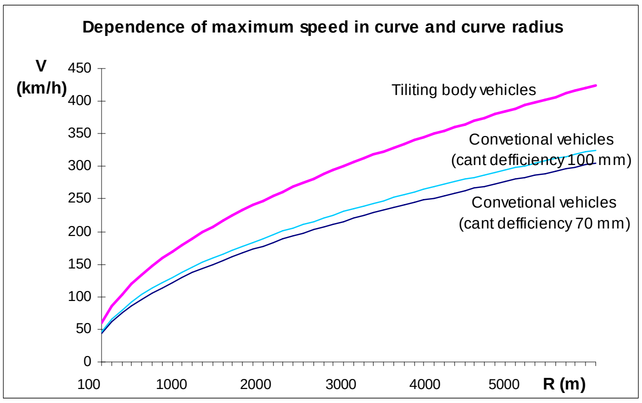

Fig.5 Relation between maximum speed in curve and curve radius

It can be seen that titling body vehicle can reach remarkable higher speed in small curve diameter comparing to conventional vehicles. But increased transversal forces from higher speed acting on track are becoming limiting criterion (risk of derailment, track stability, etc.) which is given by Proudhom's formulae.

3. ATTAINABLE TRAVEL TIMES ON SELECTED ŽSR LINES

Run of express trains on ŽSR (Slovak railways) infrastructure is limited by maximum track speed, which is rather low comparing to western countries. For domestic traffic, one of the principle lines of ŽSR is the line Košice - Žilina - Bratislava.

On this line, by use of computer simulation, the existing and attainable travel times have been compared considering maximum permissible speed in curves, while the track sections were considered according to present-day (before track modernisation) of existing line sections as well as according to purely theoretical speed limits in curve. In reality, if new train units would start operation, then the exiting lines should be improved, which in turn will bring less track speed limitations also for conventional vehicles.

Energy consumption has been calculated too, as this is an important cost factor, especially at higher speed. Energy consumption will play important role in operational cost especially in future and so it should not be omitted when considering speed increase.

For analysis of run of tilting body vehicles on the Bratislava – Žilina – Košice line (return trip), we used parameters of Pendolino trains, series ETR 460, ETR 470 and ETR 480 as well as currently standard electric locomotive series 363 with train set parameters: weight 400 t, length 250 m.

The choice of standard electric locomotive series 163 was done because it is the most commonly used locomotive on this line and even in most of passenger trains (IC and expresses) hauled by Railway Company Slovakia. Certainly, when comparing with Pendolino train-sets series ETR, it has lower power and maximum speed (120 km/h). But the resulting comparison gives a picture on currently attainable travel times by standard trains and potentially achievable travel times reductions by new technology. In reality the reduction will not be as great because other limitations will occur.

The train run on the selected line Bratislava – Žilina – Košice was simulated by use of software ”Train dynamics 3“, stops only in the three towns. Program calculates theoretical run times and energy consumption. Regular run times were increased by 4 % supplement.

The results are presented in the table 1.

Tab. 1. Travel times by simulation calculations

Track data type	Train set	Regular run time (min)	Theoretical run time (min)	Energy consumption (kWh)
NORM	163 + 400 t	566,15	544,37	10498,8
NORM	ETR 460	564,5	542,79	8579,6
NORM	ETR 470	563,85	542,16	8578,7
NORM	ETR 480	564,39	542,68	8365,2
TBV	ETR 460	386,17	371,32	13387,7
TBV	ETR 470	385,87	371,03	13484,2
TBV	ETR 480	385,96	371,12	13103,9
TBV avg	ETR 460	399,29	383,94	11299,9
TBV avg	ETR 470	398,9	383,55	11384,2
TBV avg	ETR 480	399,13	383,78	11029,6

NORM - current track sections, V_{max} 120 km/h

TBV - tilting body vehicles – theoretical speed in curves, V_{max} 200 km/h

TBV avg - tilting body vehicles – current track sections, V_{max} 200 km/h

In case of theoretical speed limits for each curve increased energy consumption has remarkably gone up, as there were frequent changes in velocity (acceleration in sections with higher permissible speed).

Graphical interpretation of run diagram and energy consumption on Košice – Žilina line, theoretical sections (considering maximum possible theoretical speed in each curve on the line) is presented on the figure 6

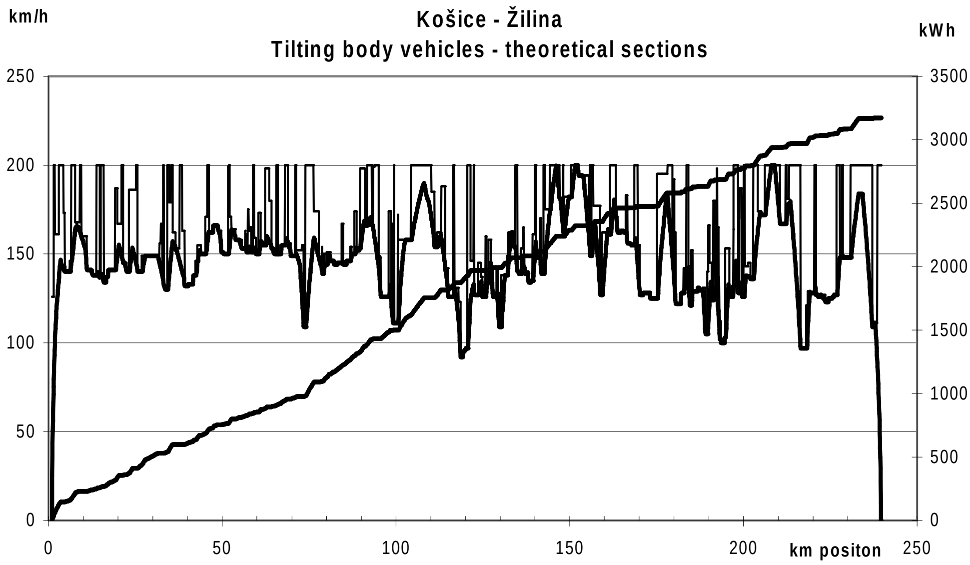

Fig. 6 Example of run diagram and energy consumption

The second type of analysis was comparison of train run on already modernised “corridor” line Bratislava – Nové Mesto nad Váhom. For comparison purposes for representative of tilting body vehicles, Pendolino series CDT 680 (Czech Pendolino) was used, for conventional train electric locomotive series 350 (max speed 160 km/h), with passenger express train, mass of 334 t, length of 180 m (7 wagons) were used.

This analysis was done with aim to compare run on the already modernised track, using both existing conventional trains and Pendolino train, but with maximum speed reduced to 160km/h. Parameters of both trains were very similar so there is no surprise that the travel times were only slightly different. Some time savings is achieved by Pendolino by lesser reduction of speed in railway station Trnava.

Comparison of travel times and energy consumption on the modernised line is presented in table 2.

Tab. 1. Travel times by simulation calculations

Train set	**From**	**To**	**Regular run time (min)**	**Theoretical run time (min)**	**Energy consumption (kWh)**
350 +334 t	Bratislava	Nové Mesto n/V	42,83	41,18	1566,6
350 +334 t	Nové Mesto n/V	Bratislava	43,71	42,03	1521,6
		Total	**86,54**	**83,21**	**3088,2**
680	Bratislava	Nové Mesto n/V	41,59	39,99	804,1
680	Nové Mesto n/V	Bratislava	42,10	40,48	777,8
		Total	**83,69**	**80,47**	**1581,9**

To explain remarkable lower energy consumption in case of train-set Pendolino (CDT 680) against the conventional train hauled by electric locomotive series 350 we enclose diagram of vehicle resistance depending on velocity for the both train sets (figure 7). From the diagram it is evident that at speed of 160 km/h the vehicle resistance of the train-set locomotive 350 + 7 wagons equals about 47 kN, while in case of tilting body unit CDT 680 only 28 kN. This, together with modern traction control, gives almost only half energy consumption on the given line. In both cases most of the line section is run at 160 km/h. Conventional train has only lower speed in Bratislava and Trnava stations, what results in a little longer travel time and more energy consumption for longer acceleration. (Energy consumption for auxiliary equipment was not considered).

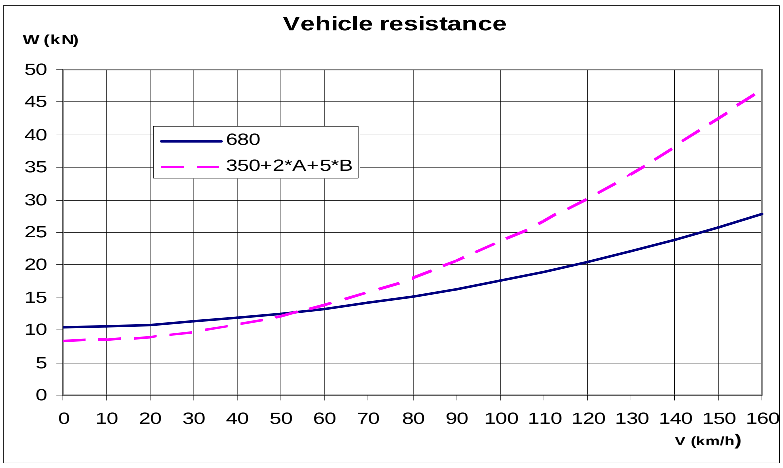

Fig.7 Vehicle resistance of train unit series 680 a train locomotive350 + 7 wagons

It should be noted that travel time reduction by use of tilting body vehicles on this section with the same speed limit is less than 4% and their use on such type of track would not have any rationale. Improved aerodynamics is not bound to tilting body vehicles and can be used also on train units of conventional design (from the tilting body point of view).

The simulation program calculates consumption for theoretical (short) travel time and not for regular one. This means that energy the consumption can be even lower (coasting was not considered).

On the other hand, additional consumption for auxiliary drives, air conditioning or heating, braking, as well as consumption during stays in stations was not calculated, though in real operation this is not negligible. Similarly, when calculating travel times, stop times in stations should be added to run times. These times are the same for both tilting body vehicles as for the conventional ones, so the relative benefit form reduced run times will be lower.

4. METHOD FOR DEFINING OPTIMUM PARAMETERS FOR TILTING BODY VEHICLES

For defining methodology for determination of optimum parameters for the tilting body vehicles we propose to use a basic philosophy of method of Balanced Score Card (BSC), which is being used for strategic management of companies, while as the strategic decision the selection of suitable parameters of railway vehicles (with tilting bodies) can be considered. The method evaluates parameters in balanced manner and in mutual relationships [3]. Defining of optimum parameters of tilting body railway vehicle can be based on the following areas (figure 8).

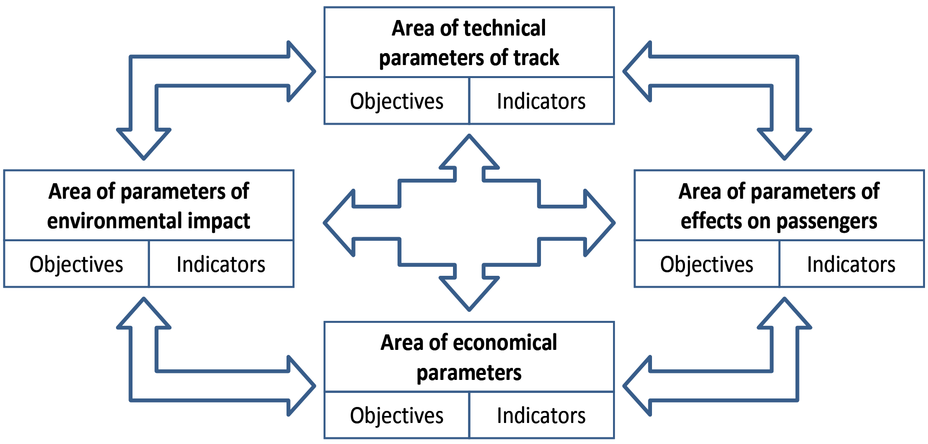

Fig.8 Methodology for determination of vehicle optimum parameters based on BSC

These parameters in principle can be divided into the following categories:

a) Technical parameters
   - parameters of railroad tracks and buildings,
   - parameters of interlocking systems,
   - parameters of traction power supply and Electrotechnical equipment.

b) Parameters of effects on environment railroad surroundings
c) Parameters of effect on passengers
d) Economic parameters
   - operational and maintenance costs,
   - disposal costs,
   - costs for increasing quality and reliability,
   - competitiveness with other transport modes.

Technical parameters

These parameters are based on valid legislation (regulations, standards,...) and mostly in designing phase of suitable type of railway vehicle it is not possible to influence these parameters as their change require high investments for modification of railway track and other connected technical facilities. Moreover, these parameters directly affect the operational safety of the rail vehicle.

Parameters of effects on environment railroad surroundings

Parameters of effects on environment railroad surroundings are also given by valid legislation but they can be affected by vehicle design and its maintenance system. Main parameters belonging to this group are especially:

- Noise emitted by the vehicle;
- Influence on soil, water and air pollution.

Parameters of effect on passengers

These parameters are most important from the point of satisfaction of passenger needs. They concern namely:

- Personal comfort during train run
- Speed of transport from place A to place B
- Train ticket price
- Traffic safety

Economic parameters

Economic parameters use to be the most important for assessment suitability of use of a railway vehicle on given railway line as operation should be economically effective. Individual types of costs related to rail vehicle operation can be affected already during the design phase.

4.1 Procedure for determination of tilting body railway vehicle

1. Creation of working group

For determination of parameters of tilting body railway vehicle it is necessary to form a working group composed of professionals in the individual areas who are capable of defining all parameters concerning the given area of tilting body vehicle.

2. Determination of goals

Based on defined parameters (point 1.) members of the working group will define objectives for each area that should be achieved in the given area.

3. Determination of indicators for each objective

For each objective (point 2.) members of working group will define indicator by which the given objective will be evaluated. The indicator must in the best possible way define importance of the objective. For each indicator it is necessary to determine source of information to evaluate the given indicator.

4. Key relationships among indicators

After definition of indicators for each objective, the members of working group will determine key relationships among indicators in the given area and key relationships among other areas with aim to find out the ways of mutual influencing of the indicators.

5. Setting the balance of fulfilment of indicators

After determination of key relationships of indicators (point 4.) the working group will evaluate each mutual relationship of the indicators and will set values of indicators so that any indicator would not be fulfilled on account of others but they will set balance in their fulfilment.

On the base of the above given procedure the working group will define the optimum parameters of tilting body railway vehicle [3].

3. CONCLUSIONS

Utilization of tilting body railway vehicles is suitable especially when there is need to increase passenger transport speed and there are not sufficient investments for construction of new high speed lines. Tilting body vehicles gain travel time savings especially by higher speed when running in curves in comparison with conventional vehicles. So the highest travel time reduction is achieved on lines with high number of curves with small curve radii. It should be carefully analyzed whether the savings in travel times will balance higher costs for new tilting body vehicles or usage of conventional trains with better aerodynamics would be sufficient.

4. REFERENCES

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