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PREPARATION OF RAILWAY INFRASTRUCTURE FOR THE OPERATION OF TILTING TRAINS

ABSTRACT

The tilting technology appeared as an idea more than 50 years ago. The idea started to be applied in the design of transport means in a more significant manner during the 80s of the last century, and has experienced major development during the last decade. The trains featuring tilting technology occupy their place on the market segment as the possibility of improving the conditions (speeds commercially 10-20%) on winding lines with curve radii not less than 250 m. They do not represent an alternative to the development of railway lines on traffic routes, but rather a span between the present and the future.

The work studies the basic technical elements of the tilting technology with the emphasis on the area of infrastructure and what is recommended and should be done on the infrastructure so that the tilting technology could render the optimal results. It is concluded that the use of tilting technology does not seek any special technical solutions, but that certain elements of the rail design require attention and should be designed in the appropriate way, at the same time not making any significant changes in the construction nor making it more expensive, but still improving the results of implementing the tilting technology in trains.

The mentioned theoretical frames are implemented in practice on the Zagreb – Split railway line where it has been found that along with the planned works on the modernization of the rail, tilting trains result in additional improvement of the riding quality and render railway passenger transport competitive to other transport modes.

KEY WORDS

railway modernization, tilting technology, infrastructure, design parameters, lines with curves, Zagreb-Split railway line

1. INTRODUCTION

At the beginning of the third millennium, the Croatian Railways have found themselves in a difficult situation. After the Croatian War of Independence, whose direct consequences were huge, and the indirect damage still greater, the rolling stock was in poor condition. In order to catch up and be compatible to the European railway traffic system, and in order to be able to satisfy the conditions of the recognized European corridors that pass through Croatia, the Croatian Railways have to carry passengers and cargo in an approximately similar way as other Central European railways.

The citizens and the industry need a reliable, safe, inexpensive and rapid transport. Road traffic is attempting to provide this, but there are restrictions such as traffic congestion, environmental pollution, excessive noise, and serious traffic accidents and damage, as well as risk to traffic participants. This provides the railway with new development possibilities, since it has been recognized as an efficient and ecologically acceptable transport system. In spite of the fact that road traffic cannot meet all the requirements, the share of railway on the transport market is falling, although it could solve many problems. The main reason for this is the dissatisfaction with the services offered. The railway is not responding in the right way and on time to the demands of the market and the users.

The appearance of tilting trains has created the possibility of filling the segment in railway traffic which is reflected in the improvement of transport services in passenger traffic on the existing lines which are aligned through hilly parts featuring unfavourable elements of the track and with many curves. If these lines are located on significant international traffic routes, then there is the need to improve the level of service, because railway on these routes is usually facing strong competition of road traffic which has been given much better conditions by the construction of new and modern infrastructure. Such approach to improving the transport service in the transition period until the construction of new or significantly improved existing lines was recognized by the managements of a great number of European railways. The International railway union (UIC), which is the carrier of the most significant activities related to the implementation of tilting trains, has joined these activities. Under the coverage of UIC a series of standards were developed, that have contributed to the standardization of this area and the uniformity of conditions that contribute to the realization of the best possible benefits provided by the tilting technology.

These potential possibilities of the tilting technology have been recognized by many countries in Europe (Italy, Germany, Spain, Finland, Sweden, the Czech Republic, Croatia, etc.) that have successfully introduced tilting trains into operation. Currently, in Europe, the fleet of tilting trains, of various manufacturers amounts to over 200 trains, and still as many are in production. The interest in introducing the tilting trains has been also shown by the countries in the world that have introduced or plan to introduce tilting trains into operation.

The greatest need for substantial improvement of railway transport service is present in Croatia from the interior towards the Adriatic. On this traffic route, very modern roads (modernized state roads and motorways) have either been constructed or their construction is in the final phase of realization. Railway lines on these corridors have been constructed mainly more than a hundred years ago with unfavourable track elements. Since the financial possibilities of the Croatian Railways and the Republic of Croatia are currently very limited, the construction of new railway lines in these corridors is not expected, and the alternative requires the use of tilting trains, in order to offer the passengers higher-quality solutions with lowest possible investments. Bringing the infrastructure into the normal design condition is a must and a procedure which is underway regardless of whether the tilting trains are introduced or not.

2. CHARACTERISTICS AND PARAMETERS OF TILTING TRAINS

The main characteristic of tilting trains is the possibility of rounding the curves at higher speeds. As the train passes through a curve it tilts as if the track cant were increased, thus compensating for the action of the lateral acceleration and centrifugal force on the passengers and prevents the phenomenon of passenger discomfort by passing through curves at a speed higher than the one stipulated for such cants. The measurements carried out in the preparation phase of introducing the tilting trains into operation show that there is no increased action of forces on the wheel-rail contact due to higher speeds in curves, compared to conventional trains, since train cases are made of light material and structure, and the propelling equipment is uniformly arranged along the whole train, thus achieving maximum axle load in trains with active tilting technology of 16-18 KN. This is less than the axle load of locomotives, which for trains of classical composition usually amounts to 22 Kn.

Apart from the construction of new or reconstruction of the existing lines, many European railways on hilly and mountain railway lines with a large number of smaller radii curves are introducing motor tilting trains, thus allowing for higher speeds in passing through curves even up to 30%. Since the track does not consist only of curves, but of straight sections as well, where the effect of the tilting technology is lower, the train speed increase achieved in

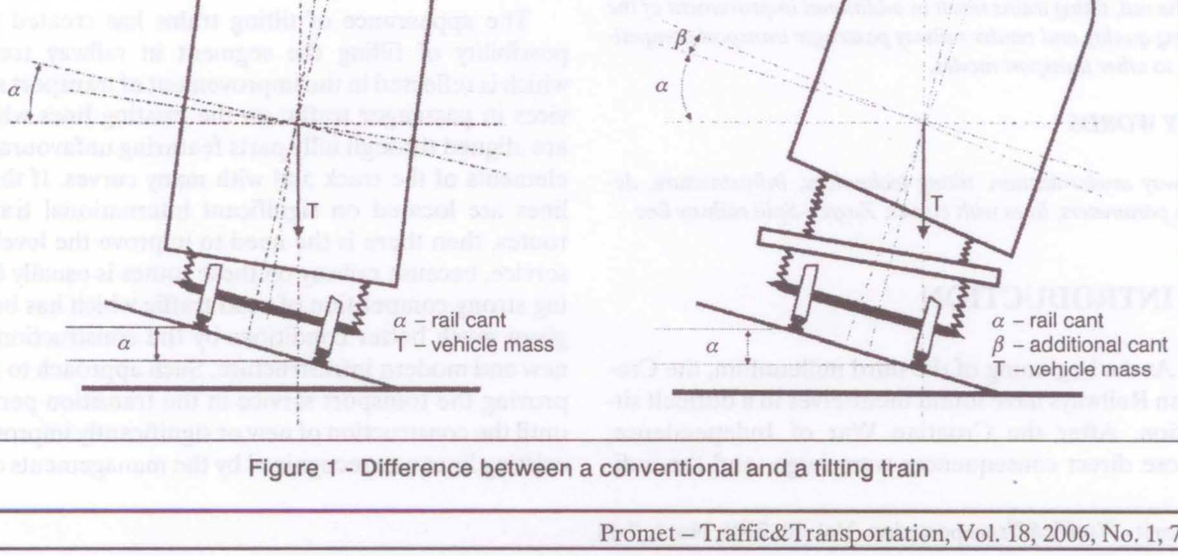

Figure 1 - Difference between a conventional and a tilting train

practice on the whole line ranges from 10-20% (depending on the proportion of curves in the whole railway line).

Figure 1 shows the basic difference between the conventional and tilting trains.

The tilting mechanisms that are installed into such trains may be:

1. mechanisms with natural tilting (passive), which allow tilting up to 3°;
2. mechanisms with forced tilting (active), which allow tilting of cars up to 8° thus achieving better results.

Tilting mechanisms can be designed as:

- hydraulic;
- electro-hydraulic;
- electronic.

The introduction of a tilting train on a certain track requires thorough measurements of all accelerations and forces at different speeds, and especially at top margin speeds, everything made possible with today's sophisticated measuring devices. Only after having completed the measurements can the exploitation speed of the train be determined for the train on the given railway line. This precisely defines the conditions of operation of a certain train on the given railway line.

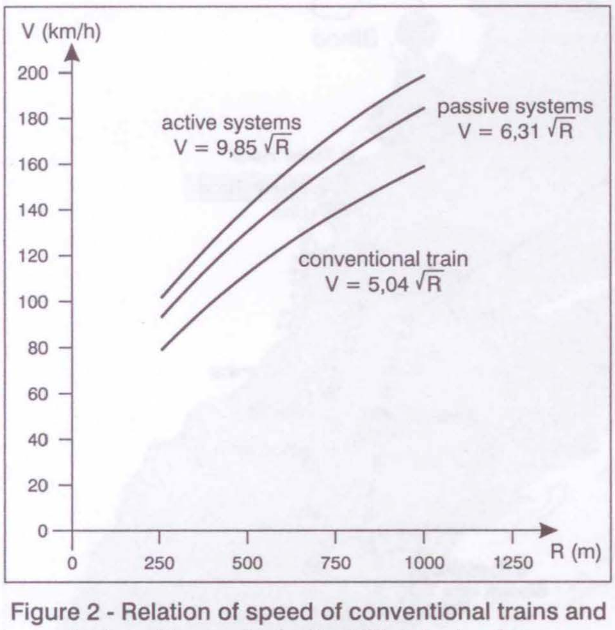

Figure 2 - Relation of speed of conventional trains and trains with passive/active tilting technology

The passive system has the restriction in the full usage of tilting technology since the set (which is a tilting one) is hauled by a conventional locomotive, which in turn represents a limitation due to its axle load (up to 220kN).

Active systems allow full usage of the tilting technology, in the sense of increasing speeds, since the axle load amounts to up to 180 kN.

The train design must insure minimal harmful impact on the environment, which refers primarily to:

- quality of exhaust gases,
- noise,
- vibrations,
- impact on the tracks,
- interference with the operation of TK[1] and SS[2] instruments.

In relation to the conventional train, the tilting train has also the following ecological advantages:

- up to 30% lower fuel consumption,
- closed system of toilets,
- cooling aggregates free of freon

The maximally permitted travel speeds are limited by the following factors (Table 1):

Table 1 - Limiting factors in achieving maximum permitted speeds of railway vehicles

Derailment safety	Y/Q < 0.8
Maximal lateral force	Y < 60 kN
Maximal force on tracks	(Y1 + Y2) < 60 kN
Maximal non-compensated lateral acceleration	1.8 m/s2
Cant deficiency	275 mm

Apart from electric tilting trains, there are also tilting diesel railcars, which are widely implemented in the regional and intercity traffic, and we distinguish:

- diesel-hydraulic, and
- diesel electric trains.

3. EXPECTED EFFECTS OF INTRODUCING TILTING TRAINS INTO OPERATION ON THE ZAGREB – –SPLIT LINE

After the end of the war and after liberating the temporarily occupied regions of Croatia, a decision was made to start the reconstruction and modernization of the Lika route towards the Central Adriatic (Split, Šibenik, Zadar). The Lika route consists of lines that were built at different times and belonged to separate traffic routes. The section of the railway line Zagreb - Karlovac - Oštarije in the length of 102.9 km was open to traffic up to Karlovac in 1865, and to Oštarije in 1873. The section of the railway line Oštarije-Gospić-Knin in the length of 218.6 km was built in the period from 1914 to 1925. The lines of the Central Dalmatian region include also the railway lines: Knin-Zadar in the length of 94.3 km (built in the period from 1962-1967) and Šibenik-Perković in the length of 21.3 km, which was open to traffic in 1877.

On the Zagreb - Oštarije - Split (424.2 km) traffic route there are three characteristic sections:

- Zagreb - Karlovac - Oštarije 102.9 km
- Oštarije - Gospić - Knin 218.6 km
- Knin - Perković - Split 102.7 km

Figure 2 shows the railway lines that connect the interior of Croatia with Central Adriatic, with the indication of possible improvements of the railway routes on the least favourable sections. The least favourable sections are located in the region between

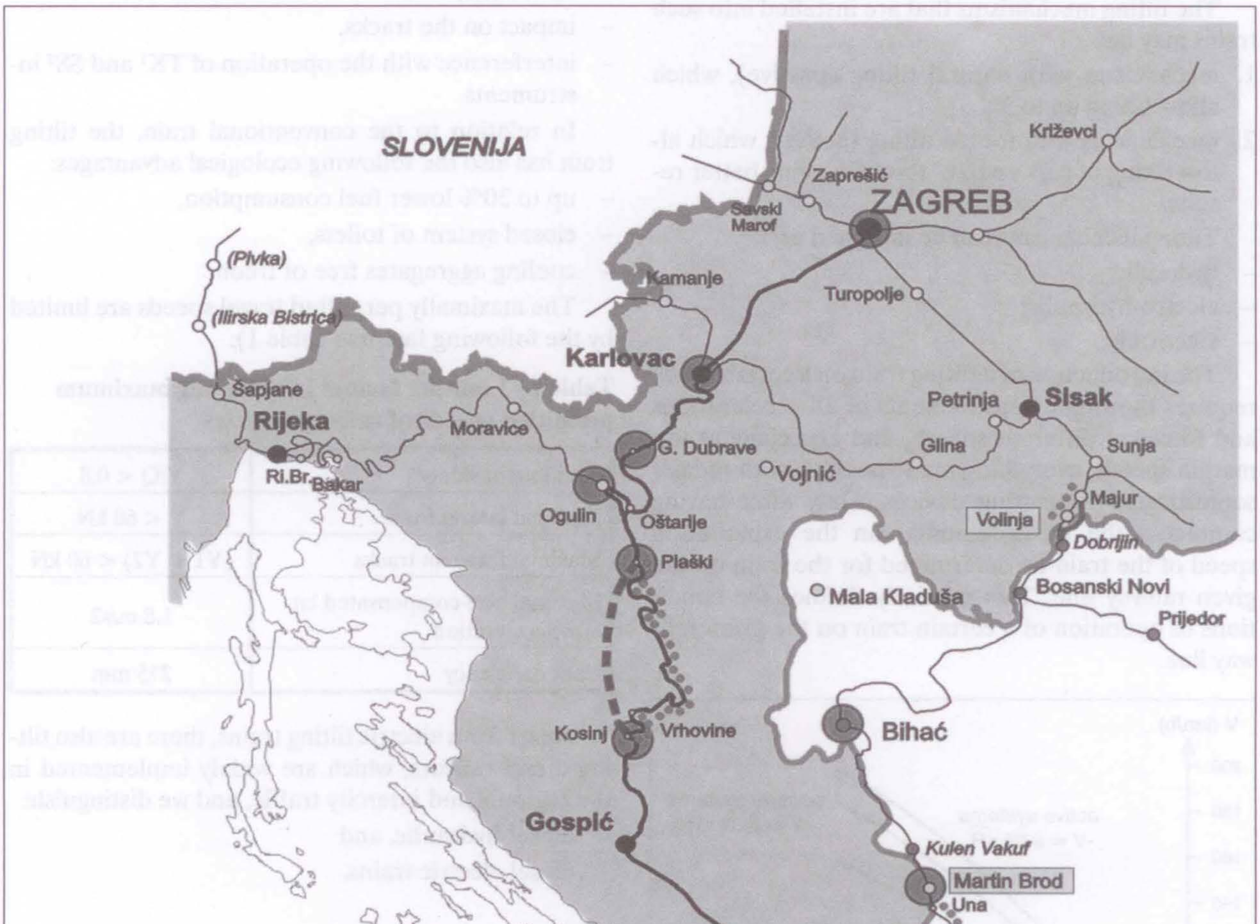

Figure 3 - Map of the existing railway lines that connect the interior of Croatia and the Central Adriatic region

the railway stations Plaški and Kosinj, and on the relation from Gračac to Knin.

Table 2 shows the elements of comparison (travel time and price of transport) of the transport services on the Zagreb – Split relation.

Table 2 - Comparison of different transport means on the Zagreb – Split relation

Transport means		Travel time [h:min]	Price (kn)
Bus	state road	6 : 30	120
	motorway	4 : 30	140
Train	tilting	5 : 45	152
	passenger (night)	8 : 00	147
Aircraft		0 : 45	460

The table clearly shows that the aircraft is the fastest means. However, this refers to the pure flight time. What should be added here is the time spent on checking the baggage before flight and the time spent on baggage reclaim after the flight, then the journey to the airport (which are both located in the suburbs – in Velika Gorica, i. e. in Kaštel Štafilić) and from the airport to the destination. When all this is considered, the total travel time amounts to 3 hours. It should be noted that the price is also three times higher than the competition.

Bus travelling achieved its maximum by using the motorway, whereas travelling by tilting train in current conditions takes only 1 hour longer. When the rail is brought into its design condition, the travelling will take about 4 hours. This alone imposes the tilting train as the optimal solution on the distances of up to 500km, which cannot be competed by bus or aircraft either regarding environment or comfort. In the mentioned conditions the tilting train is starting to provide competitive service with the tendency of improvement when all the planned works on the modernization of the lines towards Split are completed and when the travel time of the tilting train on that relation may be expected to take about 5 hours.

4. CHARACTERISTICS OF INFRASTRUCTURE PLANNED FOR TILTING TRAIN TRAFFIC

The values of the technical and exploitation parameters of the railway line which have a limiting impact on a more rational and more economical usage of the tilting trains, with the following margin values:

- curves of radii below 300m (1‰ curved track rolling resistance on the average affects the power consumption increase up to 6% in lighter and up to 20% in heavier trains),
- axle load of the railway line above 180 kN,
- allowed speeds on railway lines below 80 km/h etc. (some tilting systems are adjusted to automatically switch off at speeds below 70 km/h),
- the influence of infrastructure modernization regarding introduction of modern SS and TK instruments (inadequate SS and TK instruments can impede the increase in train speed, if the substructure of the track has been modernized and this failed to be followed by adequate modernization of the mentioned instruments).

Every investment into infrastructure quality improvement realizes favourable effects in the business area of transportation services. Therefore, this part of the relations between the mentioned business areas is the most important, and this is where mechanisms and models need to be planned which will act autonomously on the business area of infrastructure so as to improve the infrastructure quality.

According to the current condition of the railway lines, the determined needs and technology the following possibilities of implementing tilting trains can be defined:

- basic traffic system with tilting trains for speeds up to 160 km/h, which mainly operate, due to the track alignment, at a speed less than 120 km/h, but on the straight sections of the line even up to 160 km/h (for the winding railway line from Zagreb to Rijeka and to Split), since these are the lines with small curve radii (250 and 300 m),
- regional traffic system with tilting trains for the speeds of up to 160 km/h on double-track sections, i. e. 140 km/h on single-track sections of the line, which mainly operate at this speed on adjusted classical railway lines connecting two or more county centres (this includes radii corrections and other major reconstructions of infrastructure),
- traffic systems on level sections of the European corridors V and X through Croatia with tilting trains up to 220 km/h on adjusted double-track classical railway lines (this includes radii corrections and big reconstructions of infrastructure),
- special project on connecting county centres by tilting trains at increased speeds of up to 160 km/h on double-track railway lines requires significant reconstruction and modernization of infrastructure with major financial investments (could be considered after 2010).

4.1. Marginal speeds of tilting trains

Marginal speeds could be defined as speeds above which investments in additional means into the railway line and railway vehicles are necessary. These depend on the safety or technical reasons, and as such are defined in the laws, regulations and instructions.

Operating at speeds between the margins does not result in increased costs related to railway lines and vehicles. Only the energy consumption is increased for the train operating at increased speed, but within the range of marginal speeds.

For the operation of trains at speeds greater than the mentioned marginal ones, one of the conditions about the additional equipping of the lines and vehicles needs to be met, and this is related to additional financial investments. The highest investments should be done at exceeding the speeds of 100 km/h, 135 km/h and 160 km/h. Our regulations and rules very rarely mention speeds greater than 160 km/h, but from the experiences of other railway managements in Europe, the next margin of speed is 200 km/h (but with minor financial and investment consequences for exceeding the one of 160 km/h). For high-efficiency railway lines the marginal speed (maximal) is 160 km/h, and for high-speed railway lines, the marginal (minimal) speed is 200 km/h. Therefore, high-efficiency railway lines are very widespread throughout the railway networks in Europe and the world. These are usually double-track, electrified lines, well equipped and intended for combined transport. They yield greatest effects both in passenger and in cargo transport.

These facts are given so as to explain why the maximum speed of 160 km/h has been determined as the marginal speed for high-efficiency line, and for high-speed line the minimal speed of 200 km/h. These speeds have not been chosen incidentally, but have rather been determined due to technical, safety and economic reasons.

4.2.1. Track construction for trains with tilting technology

1. On railway lines operating trains with tilting technology the track construction is recommended which consists of the following structure elements:
   - rail of type UIC 60,
   - continuous welded track,
   - track gradient towards the centre of the track 40:1,
   - prestressed reinforced concrete sleepers of mass greater than 260 kg and minimal lengths of 2400 mm or wooden sleepers 2600 mm long,
   - axes gap between sleepers 600 mm,
   - indirect or direct elastic rail fastening to the sleepers,
   - ballast bed of gravel of the size and stipulated granulometric composition and quality, of minimum 300 mm thickness,
   - below the bottom surface of the rail and the width of minimum 400 mm in front of the shoulder,
   - in curves the stipulated measures for increasing the lateral track resistance are implemented.
2. The trains with tilting technology can also operate on railway lines with other track structures, with certain limitations depending on the type and operating condition of the tracks according to technical conditions approved by the infrastructure manager.

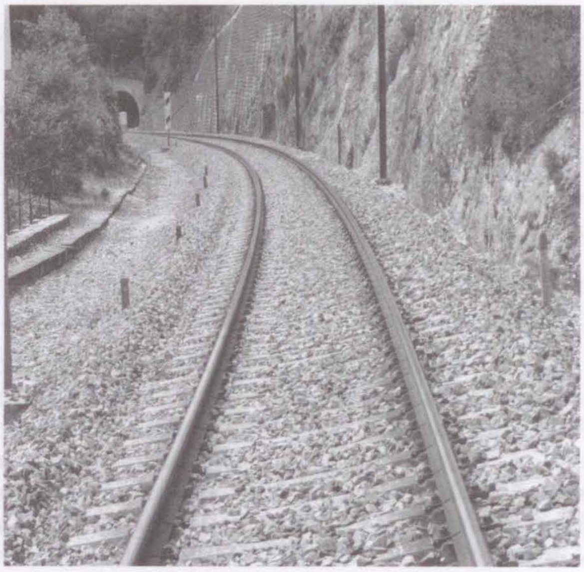

Figure 4 - Example of track structure intended for trains with tilting technology

4.2.2. Marginal values of geometrical parameters for the usage of tilting technology

1. Additional restrictions of the maximum allowed cant h_{max} of the curved track are introduced in the following cases:
   - in turnouts with curve, h_{max} = 100 mm
   - on steel bridges with wooden sleepers without ballast bed, h_{max} = 150 mm
   - on tracks along platforms, h_{max} = 130 mm
   - on level crossings, h_{max} = 130 mm.
2. Depending on the size of the curve radius, the maximum allowed cant deficiency I_{max} amounts to:
   - in curves of radii $R \geq 400$ m, I_{max} = 275 mm (for $p = 1.80$ m/s^2)
   - in curves of radii 240 m $\leq R <$ 400 m, I_{max} = 240 mm (for $p = 1.57$ m/s^2)
   - in curves of radii $R <$ 240 m, I_{max} = 210 mm (for $p = 1.37$ m/s^2)
3. Since at speeds lower than 70 km/h the tilting technology system does not function, in this speed range the highest allowed cant deficiency amounts to I_{max} = 130 mm (for $p = 0,85$ m/s^2)
4. Additional restrictions of the maximum allowed cant deficiency I_{max} are introduced in the following cases:
   - in turnouts with curves I_{max} = 180 mm

- on steel bridges with wooden sleepers without ballast bed, I_{max} = 180 mm,
- on tracks with rails of type S-49 I_{max} = 240 mm,
- on tracks with rail gradient in relation to the centre of tracks 20:1, I_{max} = 240 mm
- on rail sections subjected to strong side wind, I_{max} = 180 mm

4.2.3. Marginal values of kinematic parameters for the usage of tilting technology

1. Change of cant in time unit $\frac{dh}{dt}$ during ride in the transition curve with straight cant ramp may amount to a maximum:
   - for train speeds V > 120 km/h $\frac{dh}{dt}$ = 70 mm/s
   - for train speeds V ≤ 120 km/h, $\frac{dh}{dt}$ = 60 mm/s
2. Additional restrictions of cant change in time unit in passing the transition curve with straight cant ramp in turnouts with curves and on steel bridges with wooden sleepers without ballast bed are the following:
   - for train speeds V > 120 km/h, $\frac{dh}{dt}$ = 60 mm/s
   - for train speeds V ≤ 120 km/h, $\frac{dh}{dt}$ = 50 mm/s
3. Change of cant deficiency in time unit in passing the transition curve with straight cant ramp may amount to a maximum of $\frac{dh}{dt}$ = 140 mm/s.

4.2.4. Marginal values of axle loads

Tilting trains operate with higher rail cants and, accordingly, act on the rails with greater load than the conventional trains. Therefore, the axle loads should be as low as possible and the tilting system should be of the highest possible quality of structure.

The limiting of axle load has major impact on the marginal values of the leading force (Y) and wheel force (Q) in relation to the tracks load.

Marginal value of torsional track load has been determined by the *Prud'homme* formula which is:

$$\sum Y = \alpha\left(10+\frac{P_0}{3}\right)[\text{kN}]$$

where:

Y – lateral leading force [kN]

P_0 – vertical static axle force [kN]

α – value of coefficient defines minimal requirements for line stability, and is used for all types of sleepers and for the lines with minimal mass amounts to 46kg/m. The starting point is 0.85 (for cargo wagons) to 1 (for passenger wagons).

The lower the axle load, the greater the effect of *Prud'homme* formula. The axle load should not exceed 180kN.

If the values of forces Y and Q are connected to axle load, then the dynamic component of these forces depends on the derived rail geometry and on the quality of the tilting system which dampens the rail stress to a greater or smaller extent. The design of the tilting system also affects the value of lateral force Y, and it affects the fulfilment of the *Prud'homme* and Y/Q criteria which are of crucial significance for the assessment of the rail strength.

Consequently, we distinguish two types of rail systems:

1. "normal" rail systems, for which *Prud'homme* assessments are used,
2. "modern" rail systems (massive rails), that have higher hardness, strength and higher resistance to horizontal, vertical and lateral influences.

5. POTENTIAL TILTING TRAIN LINES

Today the implementation of tilting trains is one of the possibilities for significant increase in speeds and in the quality of passenger traffic with relatively low investments into infrastructure.

In considering the strategic directions of traffic orientation within Croatia, and considering also the assigned European traffic corridors V and X, the tilting trains in Croatia could be introduced on the following lines:

- Zagreb - Rijeka,
- Zagreb - Split (via Lika),
- Zagreb - Varaždin (Čakovec) and
- Zagreb - Osijek (Podravska magistrala).

If we consider the orientation of Croatia towards the West, the tilting trains could be introduced on the following routes:

- Zagreb - Ljubljana - Munich and further,
- Zagreb - Ljubljana - Venice and further,
- Zagreb -Zidani Most - Vienna and
- Rijeka - Zagreb -Koprivnica - Budapest.

Logical expansion of the network of these trains towards Bosnia and Herzegovina and further eastwards is expected later. Special group of tilting trains could consist of tilting trains for leasing to tourist organizations for the needs of occasional transport of passengers in Croatia and abroad. The introduction of tilting trains can be divided into two groups:

1. one group are tilting trains towards neighbouring countries,
2. the second group are tilting trains on national lines.

6. CONCLUSION

According to the UIC leaflet 703[3] and according to the Regulations 314[4] (its amendment from 2004) it has been concluded that the trains that use tilting technology do not require any special design elements regarding railway infrastructure. Special design of the rail alignment is not necessary, nor the possible special technical solutions, but the same infrastructure is used which had been planned for the operation of classical (conventional) trains on all their elements (turnouts, tracks, signals, etc.)

The tilting train uses the existing infrastructure by tilting the case and therefore travelling at higher speeds than conventional trains. Their efficiency is best expressed on hilly and winding lines.

There are two basic conditions of using the tilting trains:

1. axle load is not to exceed 180 kN,
2. usage of active tilting technology.

These two conditions allow train travelling at up to 28% higher speed (theoretically), and 10-20% higher speed (in practical implementation) on winding lines along the whole length of the lines.

In their network, the Croatian Railways own the railway lines which connect the region of Central Adriatic with the interior of the country, and which were constructed more than 100 years ago. They feature lots of curves and mountain barriers were overcome by railway lines of high ascents and small curve radii. They were constructed at the time of steam haulage when these track design elements were optimal. However, over the years these lines have been modernized by purchasing and installing higher-quality and more advanced equipment in the tracks, but the basic rail alignment elements have remained unchanged. In order to upgrade the service quality on such railway lines the tilting trains have been purchased.

After having analyzed the railway line studied in this work (Zagreb – Split) it has been found that the whole section of the railway line in the length of 423 km has about 50% of curve alignment and as such it is very appropriate for the use of trains that use tilting technology.

By the analysis of the whole rail track it has been found that the market elements set by the competitive traffic branches (first of all roads), regarding cutting of the travel time and reducing the comfort, have imposed very high requirements in this sense. In order to keep the competitiveness of the railways to these market requirements, a service should have been offered which could approach this level of service (even to go beyond it in some segments). The analysis has determined that the tilting train, as such, provides positive answers to all the questions, and primarily regarding comfort, speed, ecological suitability, and even the price.

One of the objectives of the Traffic development strategy of the Republic of Croatia is also a more uniform regional development. Significant contribution to this objective may be provided by the railways as well, and a real example for that is the railway line (Zagreb)-Oštarije-Gospić-Knin-Split/Šibenik and Knin-Zadar. It provides also its share of the contribution to the Adriatic orientation of the Croatian development.

In order to insure the necessary travelling speed, the infrastructure requires certain interventions regarding modernization, but not exclusively because of the tilting trains, but also because of the classical trains (both for the tilting and for the classical trains identical technical solutions are used regarding railway infrastructure). These are precisely the reasons why the tilting technology does not require any special technical and technological solutions. However, the recommendation has been accepted, which is given in UIC instructions UIC 703 and UIC 518[5], that have also been accepted in a way by the Croatian Regulations 314, with determined standards for the construction and modernization of railway lines due to the usage of tilting technology. Since the railway line Zagreb – Split partly passes through the Pan-European Corridor V_b (Zagreb – Oštarije), and partly the connecting Corridor (Oštarije – Split) V_{b1}, the construction of a higher quality railway line is required as well as installation of the respective elements (tracks, concrete sleepers, etc.) on the mentioned railway line.

By comparing the speed regime of the railway line Zagreb – Split, i. e. the condition before modernization and the condition after modernization, it is obvious that the speed increase, as such, requires certain technical solutions, and not the tilting train, as such. Due to the speed increase, for all the train categories, it is necessary to carry out a general overhaul of the railway line (especially on the section Oštarije – Split), to install a new SS system with remote traffic control, to reconstruct the railway stations for the installation of new turnouts that allow faster traffic both straight and in turning. It is also necessary to protect the unprotected level crossings at least by a visibility triangle, and due to the increased number of trains and their speeds the number of level crossings should be reduced to a minimum.

The analysis of the mentioned railway line has shown that the introduction of tilting trains substantially raises the level of the transportation service at the very start, so that the train travelling time is eventually reduced by about 15% (which is about 1h) compared to the classical trains. Thus, the level of service is raised to the one dictated also by road transport. Railway with the travelling time of 4.5 h from the centre of Zagreb to the centre of Split becomes, in a way, even competitive with the air traffic on the mentioned relation.

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SAŽETAK

PRIPREMA ŽELJEZNIČKE INFRASTRUKTURE ZA UPORABU NAGIBNIH VLAKOVA

Nagibna tehnika kao ideja pojavila se prije više od 50 godina. Primjena te ideje kod konstrukcije prijevoznih sredstava značajnije se počela primjenjivati u osamdesetim godinama prošlog stoljeća, a veli razvoj doživljava u posljednjih deset godina. Vlakovi s nagibnom tehnikom na segmentu tržišta zauzimaju mjesto kao mogućnost poboljšanja uvjeta (brzine komercijalno 10-20 %) na zavojitim prugama kod kojim polumjeri zavoja nisu manji od 250 m. Oni ne predstavljaju alternativu razvoju pruga na prometnim pravcima, već čine premošćenje od sadašnjosti prema budućnosti. U radu su obuhvaćeni osnovni tehnički elementi nagibne tehnike s naglaskom na područje infrastrukture i što se preporuča da je potrebno obaviti na infrastrukturi da bi nagibna tehnika dala optimalne rezultate. Konstatira se da upotreba nagibne tehnike ne traži posebna tehnička rješenja, ali da se kod pojedinih elemenata konstrukcije pruge treba obratiti pozornost te ih izvesti na traženi način a da se pri tomu bitno ne mijenja i poskupljuje izgradnja, a oni mogu poboljšanim rezultate primjerne nagibne tehnike kod vlakova. Navedeni teoretski okviri u praksi su primijenjeni na pruzi Zagreb-Split gdje je ustanovljeno da uz predviđene radove na modernizaciji pruge, nagibni vlakovi donose dodatno poboljšanje kvalitete prijevoza, i željeznički putnički prijevoz čine konkurentnijim ostalim vidovima prijevoza.

KLJUČNE RIJEČI

modernizacija željeznice, nagibna tehnika, infrastruktura, parametri konstrukcije, zavojite pruge, željeznička pruga Zagreb-Split

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