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Systems and subsystems of track, control and management of high-speed railway

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Abstract. The article discusses the following issues: according to the current level of development and equipment of the existing network of railways in Ukraine, it is necessary to state the determination of the gauge of the high-speed line; the main characteristics of the high-speed rail system and the general requirements for laying the line; track systems and subsystems, as well as including their movement and control on free terrain, ensuring the safety of operation and transportation of passengers with the declared conditions of comfort and speed; the distance between the centres of the tracks increases in proportion to the speed of movement of passenger flows, which requires additional arrangement of the roadbed, taking into account the radii of the curves, the elevation of the outer rail, the angle of descent and ascent of the track, the equivalent taper, the slope of the rail, the profile of the rail head, such as rail and sleepers; lateral and vertical forces acting on the track. In order to ensure traffic safety at the maximum permissible speeds, it is necessary that the indicated vertical and lateral forces (static and dynamic) meet the requirements, which in turn depend on the above factors.

1. Introduction

The geographical position of Ukraine is traditionally considered to be the crossing point between the Baltic and Black Seas, the border between Europe and Central Asia. With an area of 603,549 square kilometers, about 1300 km from west to east and 900 km from north to south, Ukraine is the largest country in all of Europe, slightly larger than France. Based on the successful introduction of high-speed rail in Europe and around the world, the following conclusions can be drawn:

- Countries that have established high-speed rail systems have significant national goals that contribute to their achievement;
- These countries were ready for huge investment costs, as they were convinced of the need for these projects;
- In Europe, the possibility of unification and interaction of transport systems is considered as a factor for joint work of all countries of the European Union;
- In Japan, high-speed rail is the main means of transportation that contributes to the development of the country's economy and tourism.

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Based on the foregoing, Ukraine needs to put into operation high-speed railways that will meet all the requirements for the design, maintenance and operation of systems [1, 2, 4].

2. Track subsystem

To maximize the operation of trains, the lines of the high-speed network of Ukraine should be designed in such a way that trains with a length of 400 m, with a maximum weight of 1,000 tons, moving at a speed of 350 km/h or more, correspond to the dimensions of the track presented in this article [3, 5, 8].

The track subsystem of a high-speed railway system includes all permanent stationary devices that serve to perform the following functions in accordance with the basic requirements:

- Keeping vehicles on track, including moving and steering them in clear areas, and installing safety equipment to ensure this function is performed. Boarding and disembarking passengers from trains at stations.
- Hence, permanent stationary devices include:
- Track sections without directional switches and crossings,
- Turnouts and level crossings used to change the direction of movement of vehicles,
- Structures such as bridges and tunnels that allow obstacles to be crossed under special conditions,
- Necessary safety equipment as well as protective equipment to maintain the integrity of the subsystem,
- Associated structures at stations (platforms, driveways, etc.).

3. Infrastructure

3.1. Line location

The design of high-speed lines should meet the following general requirements aimed at satisfying the main characteristics of the high-speed railway system presented in Table 1

Table 1. Main characteristics of the high-speed rail system.

Main characteristics of the high-speed rail system	General requirements for laying lines
Straight line between big city centres	Using the existing infrastructure of the main stations of large cities
Connection to urban/suburban and other rail services at hubs	Use of existing long-distance train equipment for high-speed trains, if the project does not allow, the shortest system of passenger movement, delivered by local or regional modes of transport
Reduce trip duration as much as possible	Design as straight as possible line lay between main stations with the greatest possible length of track sections with high-speed railway parameters. Design with the smallest distance between platform and standard train door placement
Minimize infrastructure costs	Design of all infrastructure subsystems with parameters standard for high-speed lines, which excludes the use of road and railroad crossings, except for high-speed overpasses and switches at junctions. Minimize line lengths by leveraging standard high-speed train performance as well as optimizing maximum allowable slopes and curves

Minimize operating costs	Designing a depot for maintenance of infrastructure and rolling stock, taking into account the location of the routes
Minimize the cost of project implementation stages	Design compatibility solutions high speed and existing lines, so that high speed trains can run on existing lines

These principles for the introduction of high-speed rail in Ukraine should be carried out taking into account the relevant criteria and parameters for the location of the track, which are described below [6, 7].

Compatibility of high-speed lines with traditional lines is part of the operational requirements for the gradual implementation of a high-speed rail network. Possible scenarios should cover all subsystems to achieve the required compatibility [9].

3.2. Distance between track centers

An important condition is the location of the tracks of high-speed lines at a considerable distance from each other, since with the passage of two trains, the possible sum of speeds will be 750 km/h. Too close passage of two trains can lead first to a sharp increase and then to a sharp decrease in pressure between the cars. Repetitive pressure on windows can cause glass fatigue, which can cause windows to break.

Thus, to maintain safety, the two tracks in each direction must be farther apart than on conventional lines.

Adequate space must be provided along each track used for high-speed trains; this space should allow passengers to disembark from the train on the side opposite to the adjacent tracks, if the latter are operated during the disembarkation of passengers. In places where tracks are located on engineering structures, a protective parapet should be installed on the side of the tracks so that passengers can safely exit.

At the design stage, the minimum distance between the centres of the tracks of lines specially built for high speeds up to 350 km/h should be 5 m.

3.3. Earth bed

Due to the conditions described in the previous paragraphs, the width of the top layer of the subgrade for a line with two tracks should be at least 14.5 m. The subgrade for high speed lines is located deeper than for conventional lines. Typically, a layer of concrete and a tarmac of crushed stone (like on a highway) is laid, followed by ballast to prevent soil movements affecting the alignment of the railroad. For drainage purposes, the subgrade must be constructed with a 4% cross slope from the centre of the base of the straight track. For the feasibility study, embankments and branches should be constructed in a 3/2 (base/height) ratio [10, 16].

The sub-ballast layer should be made of granular materials, 0/31.5 mm thick, 0.35 m. This will avoid puncturing the sub-layer for water drain and distribute the load evenly along the subgrade. The subgrade should be made of granular materials (0/125 mm, 0.50 m thick), you should also pay attention to the effect of deep soil freezing in winter.

In areas with unsatisfactory natural soil conditions, to increase the stability of the embankment, it is necessary to add a layer of geotextile, as well as a geogrid layer in the lower part of the embankment. To strengthen the embankment in areas prone to soil settlement, pile driving is necessary to create transitional structures to adjacent bridges and culverts. Attention should be paid to the effect of deep freezing of the soil in winter.

3.4. Curve radius

When designing high-speed lines, the minimum radius of the selected curve should be such that the failure of the outside rail to exceed the curve for the curve under consideration does not exceed the level planned for the passage of trains at maximum speed [4, 11, 15]. Thus, the minimum radius of the horizontal bend of the curve for a high-speed line designed to travel at a speed of 350 km/h should be at least 7,200 m (in exceptional cases - 5,600 m). The standard minimum for a vertical curve should be around 25,000 m which is also confirmed by the condition (1) of comfortable ride of passengers and prevention of overloading of the outer rail:

$$h_{min} = 12.5V_{max}^2(R)^{-1} - 115, \tag{1}$$

where V_{max} −maximum speed developed by passenger trains on this curve (km/h); 115 −the value of the maximum understeer (mm), calculated under the conditions of not exceeding the allowable outstanding acceleration.

Condition (1) is performed in compliance radii design and operation.

On track sections where trains run at low speed (station and siding tracks, tracks in depots and at parking lots), the minimum horizontal design radius for an isolated curve should be at least 150 m. Allowing in practice various options for laying the track, the minimum effective radius is not should be less than 125m.

Vertical laying of parking and service tracks should not include curves with a radius of less than 600m in hills and 900m in lowlands.

The sub-ballast layer should be made of granular materials, 0/31.5 mm thick, meter this will avoid piercing the sub-layer for water drain and evenly distribute the load along the subgrade. The subgrade should be made of granular materials (0/125 mm, 0.50 m thick), you should also pay attention to the effect of deep soil freezing in winter.

In areas with unsatisfactory natural soil conditions, to increase the stability of the embankment, it is necessary to add a layer of geotextile, as well as a geogrid layer in the lower part of the embankment. To strengthen the embankment in areas prone to soil settlement, pile driving is necessary to create transitional structures to adjacent bridges and culverts. Attention should be paid to the effect of deep freezing of the soil in winter [12].

3.5. Elevation and failure to exceed the outer rail in a curve

The minimum radius of the curved track, as well as the elevation of the track, determine the maximum inadequacy of the outer rail in the curve for a given speed. Insufficient excess of the outer rail in the curve is one of the elements that determine the load on the track.

Infrastructure design should take into account the performance capabilities and technical constraints of rolling stock. Acceleration and train braking and stopping requirements are very important issues to ensure potential speeds.

The recommended elevation for high speed lines should be limited to 180 mm. The lack of excess of the outer rail on straight track sections at the design stage of high-speed lines should be limited to 65mm. Higher indicators of insufficient excess of the outer rail in the curve are possible if the construction of the lines takes place in difficult topographic conditions.

3.6. Track width

The article [10, 11] describes the advantages and disadvantages of using 1.520 and 1.435 mm gauge for the Ukrainian high-speed network. The final decision on the track gauge will be made by the Ukrainian authorities.

In Europe and around the world, high-speed lines with a rail spacing (track gauge) of 1.435mm are used. This standard has been adopted by the European Union for all high-speed lines.

The track gauge corresponds to the distance between the active sides of the rail heads, measured at a height of 14.5 mm (± 0.5 mm) below the rolling surface. At the design stage, as well as during the construction and operation of the track, the track gauge must be maintained within the specified limits. It should also be noted that the figures presented in the article should be considered as “standard or standard values” with a standard base gauge of 1.435 mm.

3.7. The angle of descent and ascent of the track

Higher slope and rise angles are allowed for high-speed lines than for traditional railways. This fact is due to two main reasons. First, the line should be as straight as possible and not contain curves in order to thus reduce its length. Secondly, the faster the train goes, the less it will slow down on the rise, due to the kinematic energy accumulated by the train. The angle of descent and ascent of new high-speed lines should be limited to 35 mm/m. The average slope of the cross-sectional slope on a track section longer than 10 km should be 25 ‰ or less. The maximum length of a continuous track with an inclination angle of 35 ‰ should not exceed 6.000 m.

3.8. Equivalent taper

The interaction of the wheel and rail is a major determinant of the dynamic behavior of a moving rail vehicle. Equivalent taper plays a significant role, since it allows you to evaluate the interaction of the wheel and rail on a straight track section, as well as in a curve with a large radius.

Taking into account the axle characteristics (wheel profile and distance between the active surfaces of the wheel), compliance with these values for the equivalent taper for high-speed rail should be obtained by a suitable, well-documented selection of three components for track sections and switches: track gauge and tolerances, rail slope and rail head profile [12, 13].

3.9. Rails and sleepers

The rail curtain is the angle between the axis of symmetry of the profile of the new rail installed on the support and the perpendicular to the rolling surface. For sections of the track, the speed of which is more than 280 km/h, the rails, as a rule, are laid with a slope of 1/20, which guarantees the preservation of the design parameters of the taper of the wheel profile of the rolling stock.

However, the track may be laid with a different slope than 1/20, and it may be necessary to adopt different parameters for the “rail head profile”, track gauge and axle characteristics of the rolling stock. In this case, the compatibility of the new system with the rolling stock wheel profile in terms of its equivalent taper must be ensured.

In the design drawing of a rail, the rail head profile is defined as a sequence of circles forming a continuous curve. This curve changes as a result of rail wear and generally tends to maintain a constant shape, which must be measured using highly accurate methods to determine the equivalent taper.

The profile of the rail head must include a lateral slope from the side of the rail head at an angle of 1/20–1/17.2 with respect to the vertical axis of the rail head. This slope in the direction of the upper surface should be followed by a sequence of curves with radii of 12.7 and 13 mm, and then 80 and 300 mm, with respect to the vertical axis of the rail head.

Rail type. It is recommended to use rails of type 60 E1 (UIC 60), made of steel grade 900 A. Draft European legislation defines the flatness of the surface of class "A". It is necessary to use a jointless track, with the only exception in the areas of bridges and overpasses [4, 10, 11].

Sleepers. Based on the experience of European countries, it is necessary to use monolithic or double-block reinforced concrete sleepers with the following characteristics (these characteristics are presented as an example):

- Sleepers per kilometer: 1.666 /km
- Weight: 250 to 290 kg
- Length: 2415/2500 mm
- Width: 290 mm

3.10. Impacts on the track

Transverse and vertical forces acting on the track are important factors that determine both the dynamic characteristics of the rolling stock on the track and the fatigue characteristics of the track superstructure. In order to ensure road safety at the maximum permissible speeds, it is necessary that the specified vertical and lateral forces (static and dynamic) meet specific requirements. The infrastructure should be designed to withstand the maximum axle loads specified for the rolling stock.

The coefficient of the force of the dynamic lateral and vertical action of the wheel on the rail should not exceed the coefficient of derailing of the car from the rails. The geometrical characteristics of the wheel-rail contact area must ensure stable movement of the bogies (equivalent taper). The braking system of the rolling stock must not cause shear of the rails in the rail fastening system and/or slip of the wheels [17, 18].

The forces of influence exerted by the rolling stock on the track are determined both by the conditions associated with traffic safety and the characteristics of the track's ability to resist these forces. These forces arise exclusively as a result of contact between wheels and rails, as well as as a result of direct action on the rail of the braking equipment. These forces include:

- Vertical impact forces: static, resulting from the distribution of the weight of the rolling stock on the wheelsets; quasi-static in curves arising from the transfer of vertical loads as a result of lateral acceleration, not compensated by the elevation of the track; as well as dynamic ones arising from the geometric characteristics of the track and movement of the rolling stock.
- Track and turnouts must be designed to withstand a minimum of 16 tonnes per axle, which is the maximum dynamic axle load permissible for high-speed trains at 350 km/h.
- Lateral forces of action: quasi-static in curves, arising as a result of lateral acceleration, not compensated by the elevation of the track; as well as dynamic ones arising from the geometric characteristics of the track and movement of the rolling stock.

The track and turnouts must withstand at least the following lateral forces:

- Maximum total dynamic lateral force of the wheelsets on the track:

$$(\sum Y)_{max} = 10 + P(3)^{-1}, \tag{2}$$

where P −is the maximum static axle load (expressed in kN) of the rolling stock allowed on the given line (maintenance rolling stock, high-speed and other trains).

This limit is specific to the risk of displacement of the track on the ballast due to shear dynamic forces. The ratio of shear forces to vertical forces of the wheel:

$$Y(Q)^{-1} = 0.8, \tag{3}$$

where Y and Q are, respectively, the dynamic transverse and vertical forces of the wheel on the rail.

This limit characterizes the risk of wheel rolling on the rail and is shown in Figure 1 for the existing railways of Ukraine for different speeds.

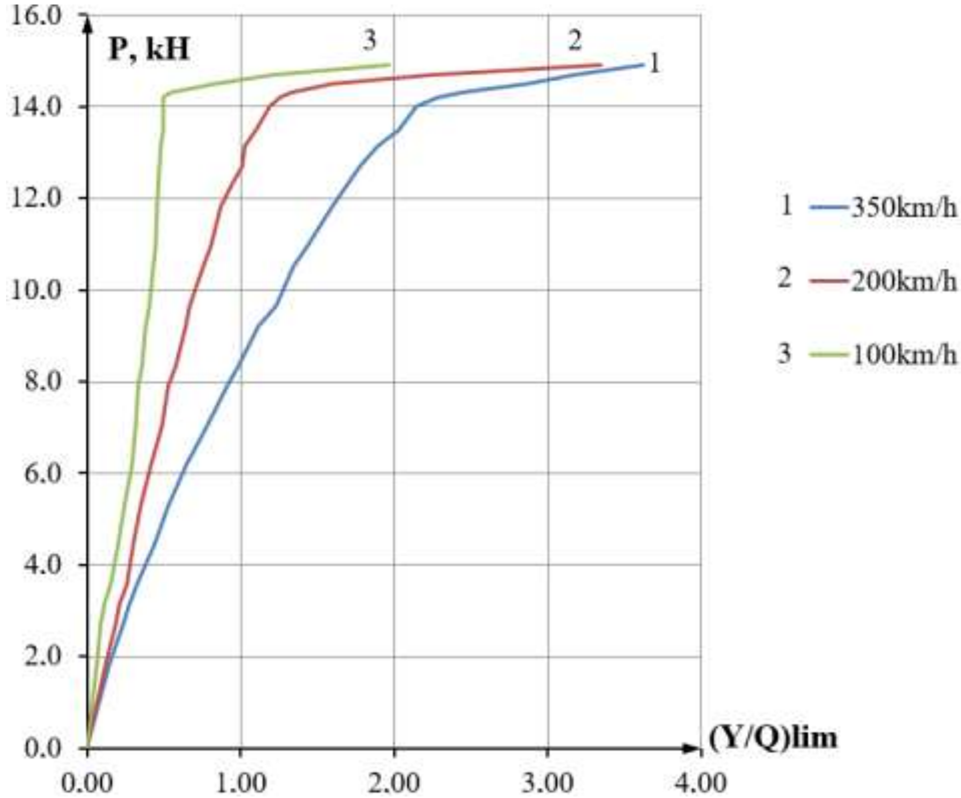

Figure 1. Limit characterizing the risk of wheel rolling on the rail from speed

- Lateral forces resulting from the acceleration and deceleration of the rolling stock during braking and acceleration.

Tracks and turnouts must withstand the transverse forces of the rolling stock, corresponding to a maximum acceleration and deceleration of 2.5 m/s^2, as well as the accompanying effects of temperature rise. The track superstructure must also withstand the lateral forces exerted by other trains that will use the line (maintenance rolling stock as well as other trains) that meet the above acceleration and deceleration rates [14].

3.11. Structural loads

Vertical, lateral horizontal and longitudinal loads on structures should be calculated using loads from load models as well as calculation methods specified in the standards for all types of rolling stock expected to operate on the line (maintenance rolling stock, high speed and other trains). Consideration must be given to dynamic effects on bridges [19].

3.12. Pointer transfers

The points of the turnouts and the marks of the cross on the turnouts and diamond-shaped crossings must be equipped with devices for securing and blocking.

Usually, it is required to comply with UIC standards 60 A 74. It is possible to use turnouts with stationary fixed switch points.

The permissible speed of movement of trains along the main and branch line of the turnout switch depends on the characteristics of the permissible speed of movement and has the following assessment conditions: strength of the elements of the turnout switch; resistance to permissible stresses and deformations; rolling stock resistance to rollover and loading; ride comfort for uncanceled accelerations and permissible impulse accelerations [20].

Dependence of the permissible train speed on the strength of the switch elements:

$$(V) = f([\sigma], \Delta x, \Delta y) \quad (4)$$

where $[\sigma]$ −permissible voltages on the limited elements of the turnout switch; $\Delta x, \Delta y$ −permissible deformations in the horizontal and vertical plane of the limited elements of the turnout switch.

Dependence of the permissible train speed on the condition of ensuring the durability of the rolling stock:

$$(V) = f(R, n, Y) \tag{5}$$

where R - the smaller of the 2 radius of the wit or the transfer curve; n - the coefficient of safety factor against overturning (sliding) of the wheel flange on the elements of the turnout switch.

Dependence of the permissible train speed on the condition of ensuring the comfort of passengers' ride:

$$(V) = f([a_{unc}], [F]) \tag{6}$$

where $[a_{unc}]$ - allowable uncanceled horizontal centered acceleration; $[F]$ - permissible vertical damping of the crew.

Taking into account these speeds, the necessary geometric parameters and design solutions of the turnouts are established.

For example, on high-speed railways in France, special turnouts are used, which allow you to maintain high speed when crossing them:

- Tg 0.0154, (length - 226 m),
- Tg 0.0218 (length - 160 m).

4. Conclusions

And this is not the whole list of necessary implementations and innovations for the successful commissioning and maintenance of a high-speed railway.

Having considered and analyzed the issues raised in the article, we can draw the following conclusions:

- According to the current level of development and equipment of the existing network of railways in Ukraine, it is necessary to state the determination of the gauge of the high-speed line, and as a result, the choice of a scenario for the implementation of standards.
- The main characteristics of the high-speed railway system and the general requirements for laying the line are significantly different and require more detailed study, taking into account the specific conditions of the terrain and operation.
- Systems and subsystems of the track, as well as including their movement and control on free terrain, ensuring the safety of operation and transportation of passengers with the declared conditions of comfort and speed.
- The distance between the centres of the tracks increases in proportion to the speed of passenger traffic, which requires additional arrangement of the roadbed, taking into account the radii of curves, the elevation of the outer rail, the angle of descent and ascent of the track, equivalent taper, rail slope, rail head profile, rail type and sleepers.
- Transverse and vertical forces on the track are very important factors that determine both the dynamic characteristics of the rolling stock and the fatigue characteristics of the track superstructure. In order to ensure road safety at the maximum permissible speeds, it is necessary that the specified vertical and lateral forces (static and dynamic) meet specific requirements. Which, in turn, depend on the above factors of these conclusions.

The studies presented in this article are analyzed taking into account investment and the results are presented in Table 2.

Table 2. Investments in high-speed transport in Ukraine.

Invested object	The size of the cost, million euros	%
High speed lines	17451.25	57.87

Stations	2173.5	7.21
Including:		
- new	897	2.97
- modernized	1276.5	4.23
Depot and repair company	693.45	2.30
Rolling stock	7665.9	25.42
Total	30157.6	100

The research presented in this article is an intermediate one and should be modified for specific operating conditions and the chosen option for the implementation of a high-speed railway.

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