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Assessment of the Structure Gauge against Characteristic Cross Sections in the Trans-European Rail System †

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Abstract: To achieve safety, accessibility, and technical compatibility in the operation of rail systems, technical specifications for interoperability are adopted to be complied with. This paper presents a study of the essential interoperability requirement "Structure Gauge" within the framework of the regulations applicable to new, upgraded, or renewed infrastructure in the rail system within the European Union.

Keywords: railway; Structure Gauge; clearance; interoperability

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1. Introduction

The European Union (EU) has established a sustainable and efficient transport policy that actively promotes the use of railways as the preferred means of transport. With the aim of improving the mobility, competitiveness, and sustainability of transport, the EU has developed a series of measures and policies that support the strengthening of railways as a preferred mobility option. These policies have focused on promoting investment in infrastructure, improving the interoperability and interoperation of rail services in member states, boosting innovation and technology in the sector, and fostering international collaboration in the development of cross-border rail networks. In this context, the railway has positioned itself as a key tool in the EU strategy to address the challenges of sustainable transport, decarbonization, and economic competitiveness in Europe.

2. Regulatory Framework in the European Union

The current European Directive (EU) 2016/797 on Interoperability [1] establishes relevant essential requirements to ensure interoperability in the trans-European rail system. These requirements concern safety, reliability and availability, health, environmental protection, technical compatibility, and accessibility to persons with disabilities and persons with reduced mobility. Interoperability means the ability of a rail system to allow the safe and uninterrupted movement of trains which accomplish the required levels of performance.

Directive (EU) 2016/797 [1] provides for the division of the Union rail system into structural or functional parts called subsystems: Infrastructure, Energy, Trackside Control–Command and Signaling, Onboard Control–Command and Signaling, Operation and Traffic Management, Telematics Applications, Rolling Stock, and Maintenance.

To meet the essential requirements and ensure the interoperability of the Union rail system, Technical Specifications for Interoperability (TSIs) are adopted: Infrastructure, Energy, Safety in Railway Tunnels, Persons with Reduced Mobility, Locomotives and Passenger Rolling Stock, Rolling Stock Freight Wagons, Rolling Stock Noise, Control–Command and Signaling, Operation and Traffic Management, Telematics Applications for Goods, and Telematics Applications for Travelers. Each of the subsystems is covered by one or more TSI and each TSI covers one or more subsystems.

The Infrastructure Subsystem includes the track, level crossings, engineering structures (bridges, tunnels, etc.), rail-related elements of stations (including entrances, platforms, zones of access, service venues, toilets, and information systems, as well as their accessibility features for persons with disabilities and persons with reduced mobility), safety, and protective equipment.

The Maintenance Subsystem comprises the procedures, associated equipment, logistical centers for maintenance work, and reserves providing the mandatory corrective and preventive maintenance to ensure the interoperability of the Union rail system and guarantee the performance required.

The Technical Specifications for Interoperability relating to the Infrastructure Subsystem INF TSI [2] lay down essential requirements for the infrastructure and part of the Maintenance Subsystems and establish the functional and technical specifications to be met by the infrastructure. Among these basic parameters, the Structure Gauge stands out.

3. Structure Gauge

The Structure Gauge in the railway context refers to the dimensions and measures to ensure the safety and proper passage of trains through the railway infrastructure, considering the presence of elements around the track such as bridges, tunnels, platforms, corridors, signals, catenary support elements, equipment, and other structures.

To establish the requirements to be met in relation to the abovementioned basic parameter Structure Gauge, the Infrastructure TSI [2] refers to the series of European standards EN 15273 Railway Applications Gauges, and specifically to EN 15273-3 Part 3: Structure Gauges [3].

The EN 15273 series of standards are essentially based on the results of scientific research and practical experience by the Union Internationale des Chemins de Fer (UIC), the worldwide professional association representing the railway sector and promoting rail transport; it has performed these functions since its foundation in 1922, which is substantiated in many publications, including leaflets UIC 505-4 [4], UIC 505-5 [5], UIC 505-6 [6], UIC 506 [7], UIC 606-1 [8], UIC 608 [9], and UIC 741 [10].

According to the EN 15273 approach, the gauge is defined as a set of rules, including a reference contour and associated rules, which define the external dimensions of the rolling stock and the space to be left free around the track.

By way of simplification, to facilitate the understanding of this approach, the gauge could be assimilated into a contract between the rolling stock and the Infrastructure Subsystems on which the reference contour is agreed as a basis. Manufacturers of rolling stock must consider the rules and effects specific to their scope and nature (suspensions, rolls, dissymmetry, equipment, accessories, expected construction defects, etc.) to manufacture vehicles of a shape and dimension that in no case exceed a contour based on subtracting space from the agreed reference contour. Infrastructure managers, for their part, must consider the rules and effects specific to their scope and nature (track movements for maintenance, track parameters, track defects, etc.) to build and maintain the infrastructure in such a way that it does not invade another contour based on adding space margins to the agreed reference profile. In practice, this is more complicated, as certain effects attributable to one or the other are shared through threshold allocation rules.

4. Types of Gauges and Parameters That Define Them

Historically, three methods of gauge calculation have been established: static, kinematic, and dynamic. The Infrastructure TSI [2] adopts the kinematic method, as it ensures the compatibility of the infrastructure with all types of rolling stock subject to its rules.

The parameters to be taken into account by the infrastructure according to the kinematic method, apart from the geometry of the reference contour, include, in the transverse direction, the center of the track, the effect of the extension of the track gauge, a part of the roll due to the dissymmetry of the vehicles, the horizontal component due to the rolling of the vehicle due to default or excess cant, the effect of cant error, the tolerances for infrastructure construction, the transversal displacement of the track between two maintenances, and the balance of the vehicle due to the oscillations produced by irregularities of the track, for a certain quality of track and speed of reference. In the vertical direction, the parameters to be taken into account by the infrastructure, apart from the geometry of the reference profile, include the vertical geometric deviation as a function of the curvature of the track, the tolerances for the positioning of the track, the cant error, the tolerances for the leveling of the track, the profile rail wear, the vertical component of vehicle roll due to excess or insufficient cant, and the effect of vehicle dissymmetry.

The general expressions for determining the lateral or vertical separation of obstacles are as follows:

$$\mathrm{B}_{\text{obstacle}} = \mathrm{B}_{CR} + \mathrm{S} + q + \Sigma_j \tag{1}$$

$$\mathrm{H}_{\text{obstacle}} = H_{CR} + \Delta H_V + \Delta H_q + \Sigma_V \tag{2}$$

where $\mathrm{B}_{\text{obstacle}}$ and $\mathrm{H}_{\text{obstacle}}$ are the horizontal and vertical components of the margins to be cleared with respect to the track axis and the running plane, respectively, B_{CR} and H_{CR} are the components of the geometry of the reference contour, S is the lateral projection to be considered by the inscription of the vehicle in a curve, $\Delta\mathrm{H}_{\mathrm{V}}$ is the vertical projection by the inscription of the vehicle in the vertical curve, q and $\Delta\mathrm{H}_{\mathrm{q}}$ are the horizontal and vertical quasistatic displacements, respectively, and Σ_j and Σ_V are the additional margins considered.

Four types of gauges are defined: Verification Limit Gauges, Installation Limit Gauges, Installation Nominal Gauges, and Uniform Gauges. The Infrastructure TSI [2] considers only Installation Limit, Installation Nominal, and Uniform Gauges.

The main difference between the Installation Limit Gauge and the Installation Nominal Gauge is the way of considering the simultaneity of factors. The Installation Nominal Gauge considers the sum of all of them, adding an additional margin to be established by the infrastructure manager. The Installation Limit Gauge considers the square root of their quadratic sum multiplied by a coverage factor of 1.2. On the other hand, the Uniform Gauge corresponds to a unique contour, established by the infrastructure manager, which includes the most unfavorable situations with significant safety margins.

It is also necessary to distinguish between Lower Part Gauges and Upper Part Gauges. The lower part refers to the region between the running plane and 40 cm above that plane; the upper part refers to the rest, i.e., the region above the plane 40 cm above that running plane. The study of Lower Part Gauges has to do with the consideration of obstacles such as low signals, parapets, service platforms, and steps, which have a particular interaction with the braking area, the bogies, etc.

5. Assessment of Structure Gauges

The Infrastructure TSI [2] states that assessment of the Structure Gauge shall be performed against characteristic cross-sections: track without cant, track with maximum cant, track with a civil engineering structure over the line, and any other location where the designed Installation Limit Gauge is approached by less than 100 mm or the Installation Nominal Gauge or Uniform Gauge is approached by less than 50 mm. After construction and before putting it into service, clearances shall be verified at locations where the designed Installation Limit Gauge is approached by less than 100 mm or the Installation Nominal Gauge or Uniform Gauge is approached by less than 50 mm.

Considering the representative characteristic cross-sections for railway design in Spain, established in the technical regulations of the national infrastructure manager Administrador de Infraestructuras Ferroviarias ADIF, standards: NAP 1-2-1.0 Metodología para el Diseño del Trazado Ferroviario [11], NAP 1-2-1.0 Puentes y Viaductos Ferroviarios [12] and NAP 1-2-1.0 Túneles [13], there are usually no issues with assessing the Structure Gauge in the design phase. The most unfavorable case arises in the tunnel sections. However, it is verified that the characteristic cross-sections to be contemplated in the projects according to the ADIF regulations provide sufficient margins.

In the construction phase, the scenario may change dramatically, especially in tunnel works that, for several reasons, have been forced to adjust the track layout due to unforeseen situations that occurred during the execution of the works, such as imposed variations in the track layout, deviations in tunneling boring machines due to unforeseen geological circumstances, etc.

In these cases, using traditional surveying instruments and techniques, such as total stations capable of measuring angles with an accuracy of up to 1″ and distances with an accuracy of up to 2 mm + 2 ppm, applying the radial method, it is possible to measure the as-built structure profiles and ensure an uncertainty better than 2 cm, which is enough for practically all cases.

If the conflictive areas were of great length or there were many critical zones, using modular track measuring devices such as track trolleys linked to total stations or laser scanners would allow equivalent results to be achieved with higher performance.

6. Conclusions

Setting as a goal the use of the railway as the preferred mean of transport, the European Union has developed an exhaustive regulatory framework that requires compliance with technical specifications for the different subsystems that make up the rail system. These standards establish basic parameters and requirements that must be compulsorily met.

Among these parameters, the Structure Gauge stands out, which ensures the safety and proper passage of trains through the infrastructure. The Structure Gauge must be assessed with reference to the EN 15273-3 Structure Gauges [3] standard, using the kinematic method and considering the Installation Limit Gauge, the Installation Nominal Gauge, and Uniform Gauge types.

The characteristic cross-sections for railway design in Spain do not cause problems in the design phase. However, in the construction phase, the scenario may change, especially in tunnels, due to unforeseen situations that may occur during the execution of works.

In these cases, the Structure Gauge of the as-built geometry can be assessed using total stations, applying the radial method, or using track trolleys linked to total stations or laser scanners, ensuring uncertainty in the order of 2 cm, which is enough for practically all cases.

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References

1. European Parliament; Council of the European Union. Directive (EU) 2016/797 of the European Parliament and of the Council of 11 May 2016 on the interoperability of the rail system within the European Union. *Off. J. Eur. Union* **2016**, *L138*, 44–101.
2. European Commission. Commission Regulation (EU) No 1299/2014 of 18 November 2014 on the technical specifications for interoperability relating to the 'infrastructure' subsystem of the rail system in the European Union. *Off. J. Eur. Union* **2014**, *L356*, 1–109.
3. *EN 15273-3:2013+A1*; Railway applications—Gauges—Part 3: Structure gauges. CEN Comité Européen de Normalisation: Brussels, Belgium, 2016.
4. *UIC 505-4: 1997*; Effects of the Application of the Kinematic Gauges Defined in the 505 Series of Leaflets on the Positioning of Structures in Relation to the Tracks and of the Tracks in Relation to Each Other. UIC Union Internationale des Chemins de Fer: Paris, France, 1997.

5. *UIC 505-5:1977*; Basic Conditions Common to Leaflets 505-1 to 505-4, Notes on the Preparation and Provisions of These Leaflets. UIC Union Internationale des Chemins de Fer: Paris, France, 1977.
6. *UIC 505-6:2006*; General Rules for Interoperable Rolling Stock Gauges (without Unloading Freight or Disembarking Passengers) in Cross-Border Traffic Between UIC and OJSD. UIC Union Internationale des Chemins de Fer: Paris, France, 2006.
7. *UIC 506:1987*; RULES Governing the Application of the Enlarged GA, GB, and GC Gauges. UIC Union Internationale des Chemins de Fer: Paris, France, 1987.
8. *UIC 606-1:1987*; Consequences of the Application of the Kinematic Gauge Defined by UIC Leaflets in the 505 Series on the Design of the Contact Lines. UIC Union Internationale des Chemins de Fer: Paris, France, 1987.
9. *UIC 608:2003*; Conditions to be Complied with for the Pantographs of Tractive Units Used in International Services. UIC Union Internationale des Chemins de Fer: Paris, France, 2003.
10. *UIC 741:2005*; Passenger Stations. Height of Platforms. Regulations Governing the Position of Platform Edges in Relation to the Track. UIC Union Internationale des Chemins de Fer: Paris, France, 2005.
11. *ADIF NAP 1-2-1.0*; Metodología Para el Diseño del Trazado Ferroviario. 1ª Edición: Enero 2021. ADIF Administrador de Infraestructuras Ferroviarias: Madrid, Spain, 2021.
12. *ADIF NAP 1-2-1.0*; Puentes y Viaductos Ferroviarios 2ª Edición: Julio 2018 + M1: Mayo 2019. ADIF Administrador de Infraestructuras Ferroviarias: Madrid, Spain, 2019.
13. *ADIF NAP 1-2-1.0*; Túneles. 2ª Edición: Enero 2023. ADIF Administrador de Infraestructuras Ferroviarias: Madrid, Spain, 2023.