EURASIAN JOURNAL OF ACADEMIC RESEARCH
Innovative Academy Research Support Center
IF = 9.3 www.in-academy.uz/index.php/ejar

SYSTEM ANALYSIS OF THE ADVANTAGES AND DISADVANTAGES OF ELECTRIC ROLLING STOCK WITH TILTING wagoN BODIES OF HIGH-SPEED ELECTRIC TRAIN

Khromova Galina Alekseevna[1]
[1]doctor tech. sciences, professor of the Department of “Electric rolling stock”,
State Transport University, Uzbekistan, Tashkent
https://doi.org/10.5281/zenodo.17786092

ARTICLE INFO
Received: 24th November 2025
Accepted: 29th November 2025
Online: 30th November 2025
KEYWORDS
Electric rolling stock, high-speed electric trains, tilting system of wagon bodies for high-speed electric train, active, passive and mixed (combined) systems for tilting wagon bodies.

ABSTRACT
The article presents a systematic analysis of the advantages and disadvantages of electric rolling stock with tilting wagon bodies of high-speed electric trains.

СИСТЕМНЫЙ АНАЛИЗ ПРЕИМУЩЕСТВ И НЕДОСТАТКОВ ЭЛЕКТРОПОДВИЖНОГО СОСТАВА С НАКЛОНЯЕМЫМИ КУЗОВАМИ ВАГОНОВ ВЫСОКОСКОРОСТНЫХ ЭЛЕКТРОПОЕЗДОВ

Хромова Галина Алексеевна[1]
[1] доктор технических наук, профессор, кафедры “Электроподвижной состав”,
Ташкентский государственный транспортный университет, Узбекистан, Ташкент
https://doi.org/10.5281/zenodo.17786092

ARTICLE INFO
Received: 24th November 2025
Accepted: 29th November 2025
Online: 30th November 2025
KEYWORDS
Электроподвижной состав, высокоскоростные электропоезда, система наклона кузовов вагонов высокоскоростных электропоездов, активные, пассивные и смешанные (комбинированные) система наклона кузовов вагонов.

ABSTRACT
В статье представлен системный анализ преимуществ и недостатков электроподвижного состава с наклоняемыми кузовами вагонов высокоскоростных электропоездов.

A tilting system is a mechanism that allows high-speed electric train cars to tilt when turning curves to improve speed and passenger comfort. It compensates for the centrifugal force acting on passengers when turning curves, allowing them to negotiate curves at higher speeds without causing discomfort similar to motion sickness [1, 2, 3].

Tilting devices reduce the impact of centrifugal acceleration on passengers when traveling around curves at normal and higher speeds. The tilt of the body should not reduce the comfort of the ride [4].

When tilting technology is used to navigate curves at speeds exceeding those permitted for conventional trains, this is referred to as accelerated curve handling or travel with increased permissible lateral acceleration (*ES level*). When a train navigates a curve with the tilting system engaged but at normal speed (with adjustable lateral acceleration or *RS level*), it is referred to as a comfort tilting technology. Comfort is achieved when the lateral acceleration in the car is close to zero; in this case, passengers do not perceive the train as moving around a curve.

The choice of a specific body tilt option is determined by the operating conditions of the rolling stock [3]. Despite the multitude of technical solutions for ensuring body tilt relative to the bogie, they can be conditionally divided into three classes: *active, passive, and mixed (combined)* [3,4,5,6].

Passive tilting system. The tilting mechanism, developed by *Talgo* (Spain), involves the car body, supported by high-lying air springs (the second stage of suspension), rotating around a virtual pivot point located above the car roof. When turning a curve, the car body tilts toward the outer rail under the action of centrifugal force (Figure 1). The tilt angle can reach 3.5 degrees. With a passive system, the car body tilts due to inertial forces as the train negotiates the curve [3,4].

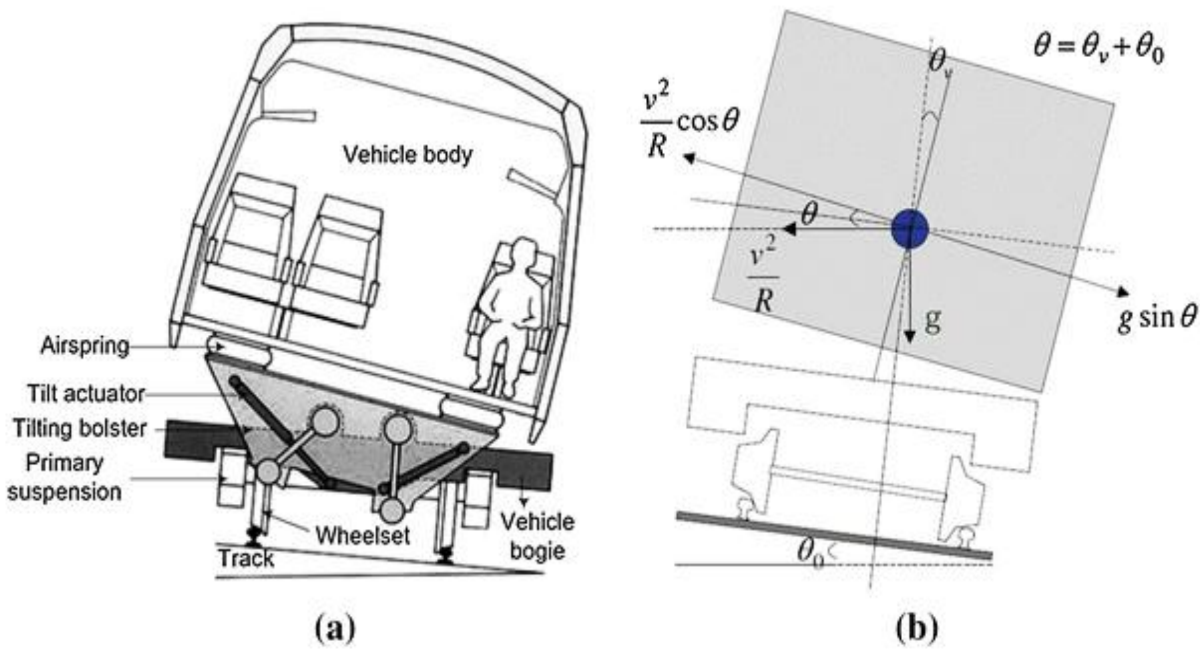

Figure 1. Schematic diagram of the passive car body tilting system for high-speed electric trains developed by *Talgo* [3,4]:

(a) – diagram of the passive car body tilting system; (b) – calculation diagram of the passive car body tilting system developed by *Talgo*.

This mechanism eliminates the need for sensors and controls, is cheaper and simpler than active tilt systems, but does not improve curve speed. In Germany, some night trains, consisting of *Talgo* carriages equipped with passive tilt systems, negotiate curves at normal speeds, as travel time is less important than ride comfort for a pleasant nighttime journey [3,4].

The tilt mechanism, developed by *Talgo* (Spain), involves the car body, supported by high-mounted air springs (the second stage of suspension), rotating relative to a virtual pivot point located above the car roof. When negotiating a curve, the car body tilts toward the outer rail under the action of centrifugal force. The tilt angle can reach 3.5 degrees. With a passive system, the car body tilts due to inertial forces as the train negotiates a curve [3,4].

Some advantages of the passive tilting system in Talgo family trains [3,4]:

- improved ride comfort on curves, while the tilting car body reduces unpleasant lateral acceleration for passengers;

- reduced travel time due to increased speed on curves; without expensive and time-consuming track improvements, speed on individual curves can be increased by 40 km/h;

- the ability to increase train speed on curves by 25% without additional investment in infrastructure modernization or reconstruction;

- improved accessibility, as the *Talgo* chassis design ensures that the car floor and platform floor are level, as well as a uniform floor height throughout the entire rolling stock.

Some disadvantages of the passive tilting system of *Talgo* family trains [3,4]:

- the need for investment in track and rolling stock, and the development and maintenance of rolling stock with an active tilting system are more expensive than conventional rolling stock;

- the need to maintain the line in proper condition. If the line's condition does not meet certain requirements, it cannot be used for high-speed electric rolling stock with tilting bodies;

- passengers have mixed reactions to the tilting process: some experience motion sickness.

Active tilt system. This system controls the tilt of the car body when cornering. The car body is tilted into the curve using a pneumatic or hydraulic cylinder. An electric servomotor can also be used. An electronic control device controls the tilt based on readings from sensors located near the first or last axle of the train (Figure 2) [5, 6, 7].

The tilt angle can reach 8 degrees. The tilt mechanism on modern rolling stock of this type begins operating at a speed of 70 km/h, with the rail elevation or change required to be at least 20 mm.

Система Pendolino (Fiat/Alstom). The tilt control system, developed by *Fiat Ferroviaria* (now *Alstom*), was first installed on Italian *ETR* trains. It was later also used in Germany on *VT 610* series diesel multiple units and *ET 411/415 (ICE-T)* electric multiple units [5].

The maximum tilt angle, adopted in this system at 8 degrees, is achieved using a hydraulic cylinder. Acceleration sensors are installed on the bogies, which transmit the resulting centripetal acceleration to the tilt control system, which calculates the required tilt angle. The sensors located on the front bogie play a key role. Their signals are used to calculate the tilt angle and the moment of its activation for the remaining cars.

The active tilt system controls the tilt of the car body when cornering, and tilts the car body into the curve using a pneumatic or hydraulic cylinder (Figure 2) [5,6,7]. The tilt of the car body is controlled by a computer, which calculates the optimal tilt angle for each curve in advance.

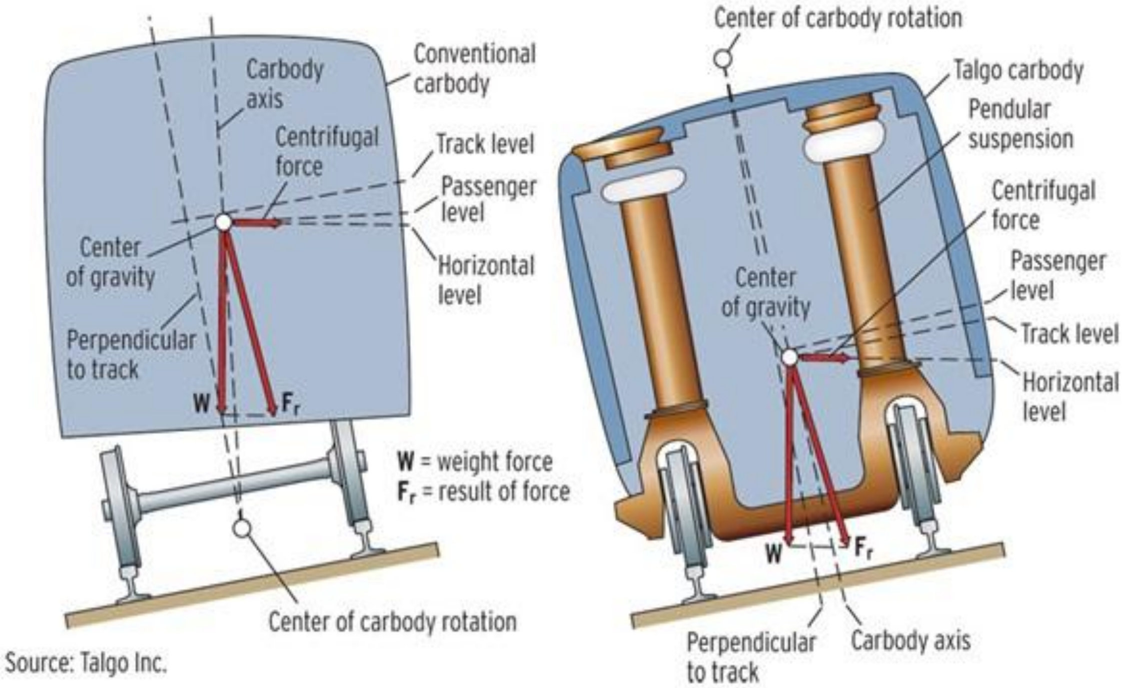

Figure 2. Diagram of an active car body tilt system when moving in a curve for high-speed electric trains for countries in Europe, Asia, America
and Australia [5,6,7].

This mechanism eliminates the need for sensors and controls, is cheaper and simpler than active tilting systems, and does not provide increased curve speed.

Advantages and disadvantages of rolling stock with active tilting systems.

Trains composed of cars with tilting bodies offer the following advantages:

- improved ride comfort on curves;
- an 8-degree tilt reduces unpleasant lateral acceleration for passengers;
- reduced travel time due to increased speed on curves.
- without expensive and time-consuming track improvements, speed on individual curves can be increased by 40 km/h.

Disadvantages of a high-speed train with cars with tilting bodies on curves:

- implementing tilting technology requires investment in both the track and the rolling stock;
- developing and maintaining rolling stock with an active tilting system is more expensive than conventional rolling stock;

- to ensure higher curve speeds, the line must be maintained in the appropriate condition (the so-called 0-profile).

- to achieve higher curve speeds, the lines must be equipped with *GNT* technology with trackside transponders to monitor the speed.

Talgo's competitive advantages [3,4,8,9,10]:

1. Independently rotating wheels with an automatic track guidance system.

Talgo is the only manufacturer of rolling stock whose wheelsets consist of wheel assemblies with individual short axles, allowing the right and left wheels to rotate at different angular and linear speeds during train travel. This feature not only improves passenger comfort but also reduces the negative impact of vehicles on infrastructure.

2. Natural car body tilt on curves.

The passive curve tilt technology (the "pendulum" tilt system) developed by *Talgo* allows for a 25% increase in train speed on curves without additional investment in infrastructure modernization or reconstruction (Figure 1).

3. The lighter and wider body of the AFROSIAB high-speed electric train manufactured by *Talgo* (Spain) with a passive car body tilt system [8, 9, 10].

One of the fundamental design principles of *Talgo* trains is to create the lightest rolling stock on the modern rail transport market. Aluminum alloys and shorter cars allow operators to offer rolling stock with such qualitative advantages as lower energy consumption and higher passenger capacity, ensured by a wider design.

Today, passive and active tilting technologies are widely used on many trains in Europe, Asia, America, and Australia, including in Uzbekistan, where the AFROSIAB high-speed electric train is used [8, 9, 10].

However, the requirements for using tilting trains vary by region. In the European Union, the speed limit for this technology must exceed 200 km/h for existing but renovated tracks, and 250 km/h for new tracks.

References:

1. Высокоскоростной железнодорожный транспорт. Общий курс: учеб. пособие: в 2 т./ И.П. Киселёв м др.; под ред. И.П. Киселёва.-М.: ФГБОУ «Учебно-методический центр по образованию на железнодорожном транспорте», 2014. Т.2.-372 с.
2. Simon Iwnicki. Handbook of Railway Vehicle Dynamics.2006. Taylor & Francis Group. - 527 p.
3. Универсальный скоростной электропоезд для железных дорог Испании. / Журнал «Железные дороги мира», №11, 2009. - С.37-40. https://zdmira.com/images/pdf/dm2009-11_37-40.pdf
4. Конкурентные преимущества Talgo [Электронный ресурс]- https://web.archive.org/web/20170116114600/http://www.talgo.com/ru/rolling-stock/technological-principles/
5. Система наклона кузовов вагонов поезда Talgo Pendular. / Журнал «Железные дороги мира», №4, 2005. - С.39-41. https://zdmira.com/images/pdf/dm2005_04_39-41.pdf

6. Достоинства и недостатки технологии наклона кузова. / Журнал «Железные дороги мира», №7, 2009.- С.60-66. https://zdmira.com/images/pdf/dm2009-07_60-66.pdf

7. Persson R. Tilting trains - Description and analysis of the present situation. A literature study / R. Persson - VTI rapport 595A. - Linkoping: VTI – 2007. 81 p.

8. Khromova G. A., Makhamadalieva M.A., Tadzhieva Sh.G. Justification of methods for improving the spring suspension systems of high-speed electric trains. // Eurasian Journal of Academic Research, Volume 5, Issue 10, October 2025, pp.39-42. Available at: https://doi.org/10.5281/zenodo.1732478

9. Хромова Г.А., Махамадалиева М.А. Разработка методики продления срока службы рессорного подвешивания высокоскоростного электропоезда Afrosiyob. // Universum: Technical sciences. 2022. №. 2 (95). С. 66-70. Available at: https://7universum.com/ru/tech/10(103)/10(103_2).pdf

10. Khromova G., Makhamadalieva M. Разработка математической модели по обоснованию рациональных параметров рессорного подвешивания высокоскоростного электропоезда Afrosiab. // Universum: Technical sciences, 2022, № 10 (103), октябрь 2022, часть 2, С. 62-66. DOI: 10.32743/unitech.2022.103.10.14404