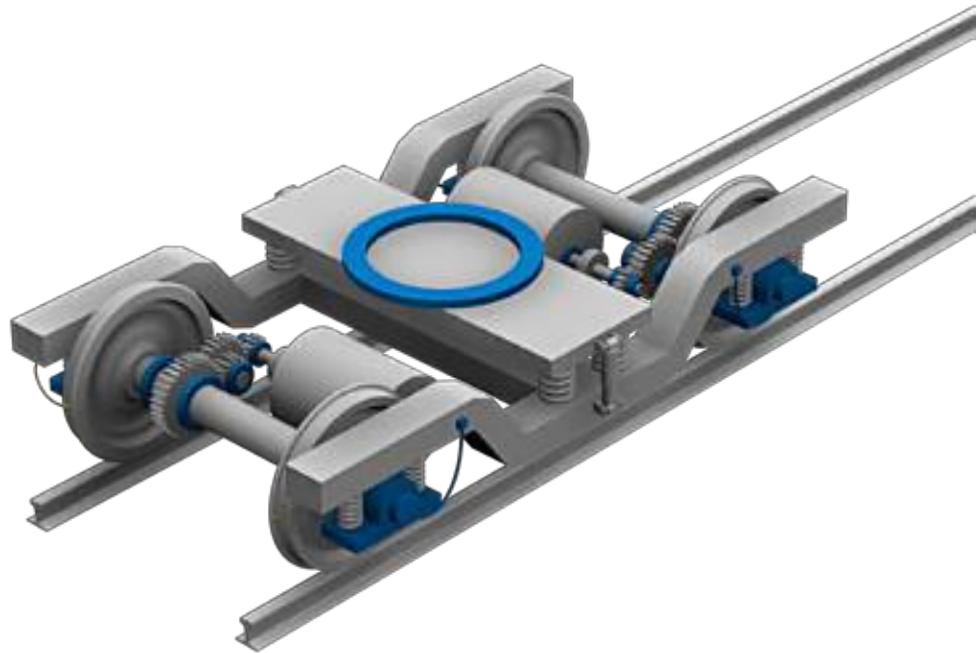


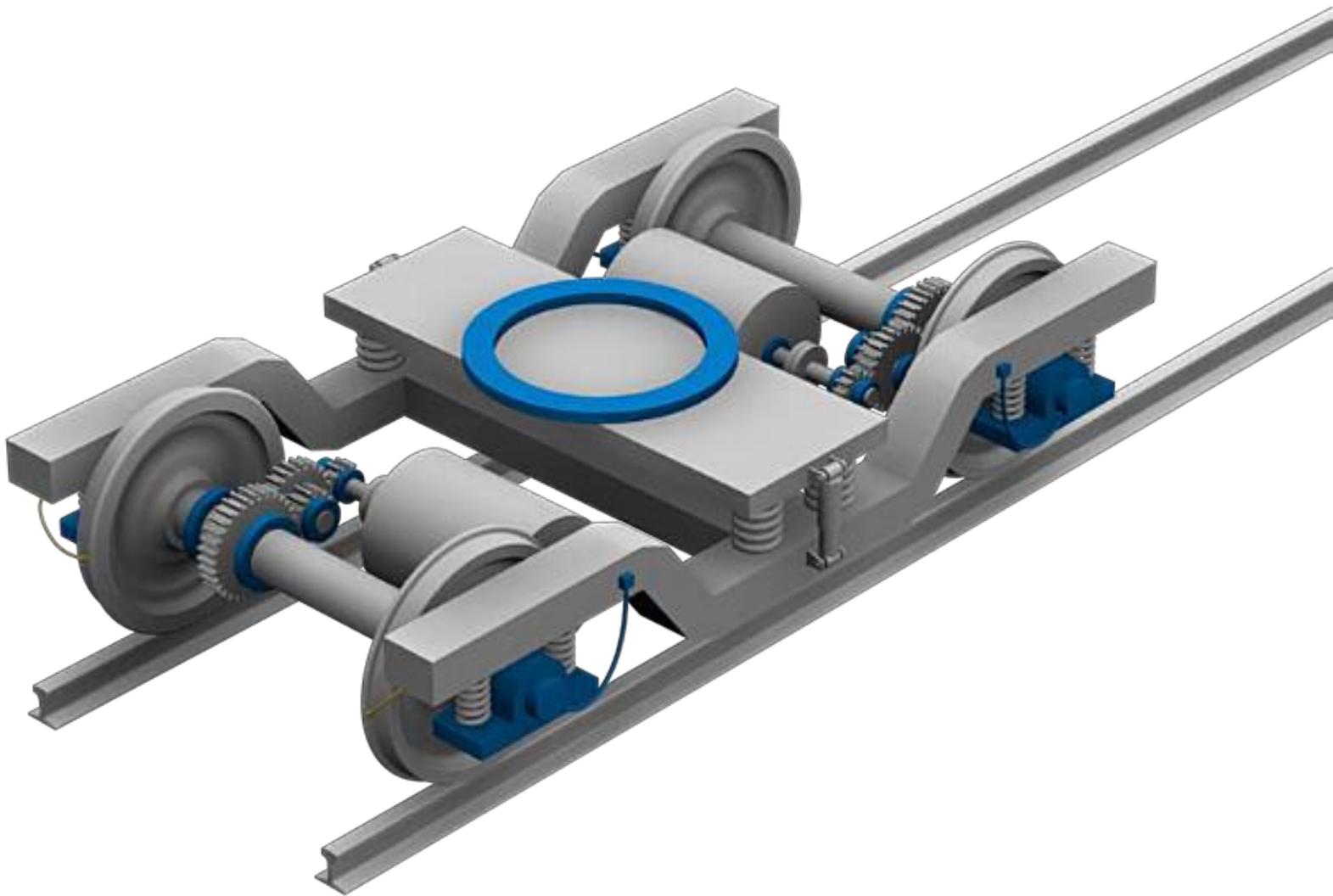
Bogie designs

Extract from the Railway technical handbook,
volume 1, chapter 2, page 24 to 41



2 Bogie designs

Design principles	25
Wheelset designs	29
Springs	32
Dampers	35
Bogie design examples	36
Earth return	40



Bogie designs

Today, very different bogie design principles are applied. The main focus of this chapter are the bogie features that are directly or indirectly related to the axlebox application. The main ones are bogie design principle parameters, guiding / suspension, primary spring and damping principles that are interacting with the design of axleboxes and bearings.

Design principles

A bogie is a structure underneath a railway vehicle body to which axles and wheels are attached through bearings. The term “bogie” is used in British English, while a “wheel truck”, or simply “truck” is used in American English. The overall term is “running gear”, which covers bogies as well as vehicles with two, or more axles without any bogies. In this case, these axles are directly fitted to the vehicle body via guiding devices and springs, and for very low speeds even without springs.

Running gears serve a number of purposes:

- support of the rail vehicle body
- stability on both straight and curved tracks
- providing ride comfort by absorbing vibration, and minimizing centrifugal forces when the train runs on curves at high-speed
- minimizing generation of track irregularities and rail abrasion

Design principle elements

Railway bogies are complex subsystems in railway vehicles and contain brake systems, drive systems including gearbox coupling and traction motors for powered wheelsets, bogie frames with secondary spring systems and the wheelset subsystems, which are basically the assembly of two wheels and an axle. In this chapter, the focus is on some general bogie design principles and especially design features that interact with the axlebox bearing system. Directly connected to the wheelset and the bogie frame is the axlebox (→ **chapter 3**) containing the axlebox bearing system (→ **chapter 4** and **chapter 5**). The axlebox is very much linked to further subsystems and components like primary spring systems, axlebox guidance, dampers, steering mechanisms of wheelsets, earth return devices as well as sensors to detect operational parameters (→ **chapter 7**) and bogie monitoring systems (→ **chapter 8**).

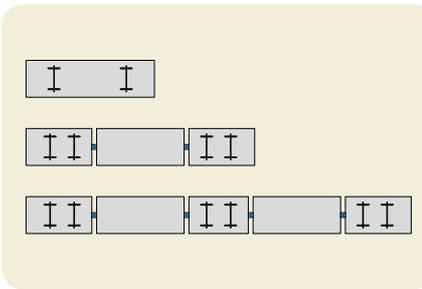
Further bogie-connected subsystems are wheel flange lubrication systems, articulation joints, slewing bearings and special plain bearings for damper supports (→ **chapter 9**).

Running gears and bogies

All kinds of railway vehicles are equipped with running gears, which can be designed as 2- or 3-axle cars or as bogie vehicles. 2-axle car design principles are used mainly for European freight cars, shunting locomotives and for sections of articulated cars such as low-floor light rail vehicles or tramways.

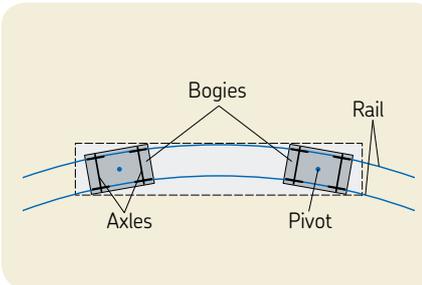
Bogie designs

Today, the majority of railway vehicles are equipped with bogies that contain mostly two axles, but in some cases, such as heavier and powerful locomotives, 3-axle designs are used. Because of the shorter axle distance of bogie designs, longer vehicles/vehicle sections can be used. On the other hand, the riding comfort of bogie vehicles is much better than vehicles equipped with axles that are supported directly by the vehicle body.

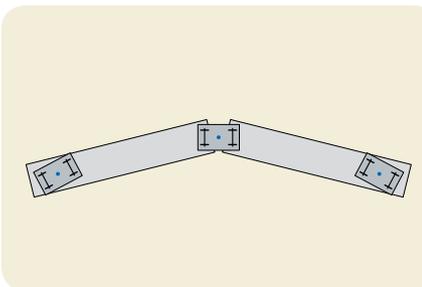


Design principles of running gears and bogies

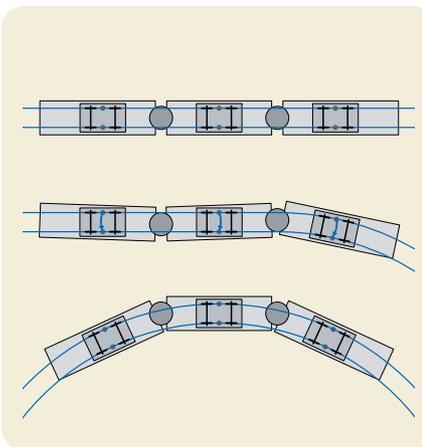
On top: 2-axle vehicle
Middle and bottom: articulated vehicles based on 2-axle running gear designs applied for light rail vehicles



Design principle of a bogie vehicle



Jacobs bogie design principle



Example of a typical low-floor multi-section tramway design

Jacobs bogie designs

A common bogie design principle, used especially for connected vehicle bodies for multiple units, special freight cars and mass transit vehicles, are Jacobs bogies¹⁾. These bogies support two body ends via one bogie. This design contributes to mass saving and running stabilization, resulting in a better riding performance for some applications.

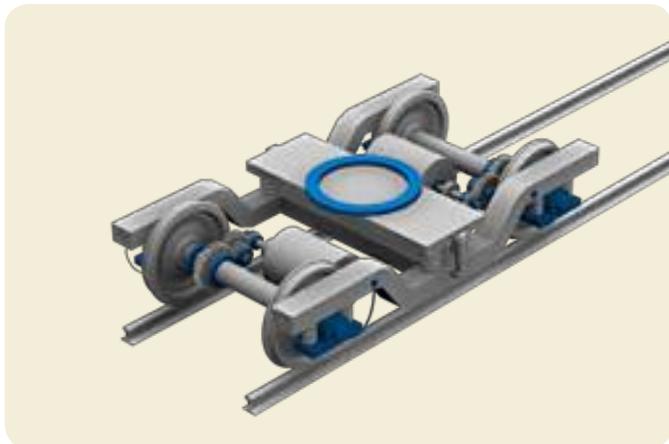
¹⁾ Jacobs bogies named after Wilhelm Jakobs (1858–1942)

Powered bogie designs

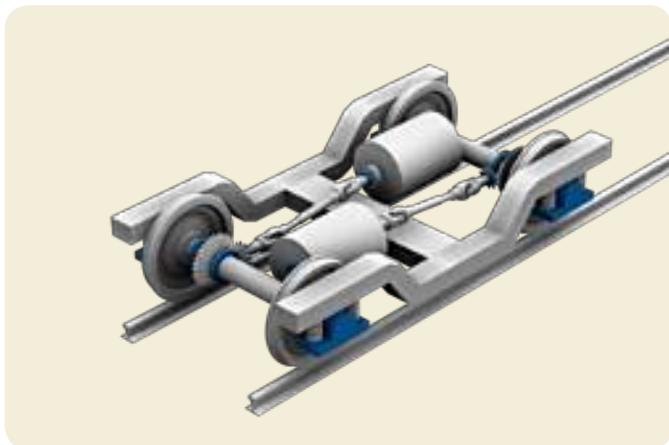
Locomotives, multiple units such as high-speed trains as well as mass transit vehicles, are equipped with powered bogies. Typical propulsion systems contain a wheelset, a gearbox and a traction motor. More sophisticated designs are equipped with hollow shafts and couplings to reduce unsprung mass.

Longitudinal propulsion (drive) systems contain a helical gearbox and cardan shafts. Hydraulic diesel propulsion systems contain mostly gearboxes and cardan shafts, connecting two bogie drives to one main gearbox and the hydraulic gearbox system connected to the diesel motor.

Powered bogie, transverse drive



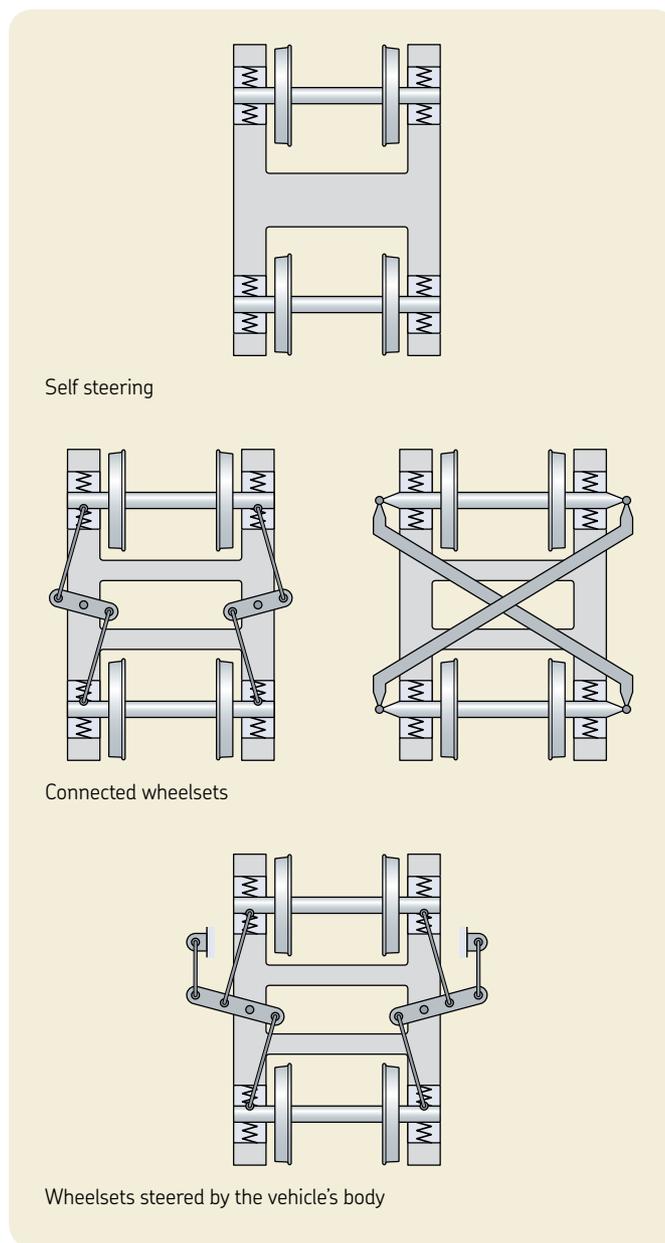
Powered bogie, longitudinal drive



Radial steering principles

To reduce the forces between rails and wheels, several radial steering design principles for wheelsets are applied. The aim of these designs is to reduce wear and noise caused by low steering forces. Designs with connected wheelsets and wheelsets connected to the vehicle body are based on lever systems that act on the wheelsets via the axleboxes.

Radial steering principles for wheelsets



Wheelset arrangement classification

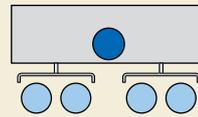
The wheelset arrangement classification is a systematic tool to sort railway vehicles by position of the wheelsets (axles), bogies and connections of vehicle bodies. There are several notations used to describe wheelset and wheel arrangements, which vary by country. Within a given country, different notations may be employed for different kinds of locomotives, such as electric and diesel.

The UIC classification scheme is widely used. It is provided by the International Union of Railways and laid down in the UIC's "Leaflet 650 – Standard designation of axle arrangement on locomotives and multiple-unit sets".

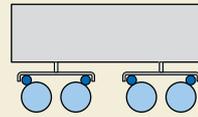
- Upper-case letters designate a number of consecutive driving axles, starting at "A" for a single axle. "C" thus indicates three consecutive pairs of driving wheels.
- Numbers designate consecutive non-driving axles, starting with "1" for a single axle.
- Lower-case "o" designates axles, which are individually driven by electric traction motors in locomotives and multiple units.
- Prime sign "'" indicates that the axles are mounted on a bogie.

Selection of practical examples:

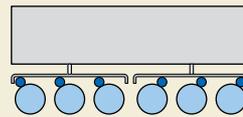
- **B' B'** two bogies or wheel assemblies under the unit. Each bogie has two powered axles, connected by driving rods or gears.
- **Bo' Bo'** each bogie has two individually-driven powered axles (i.e. via traction motors). 75% of all modern locomotives (as well as the power cars of self-propelled trains) are configured as Bo' Bo'.
- **Co' Co'** two bogies or wheel assemblies under the unit. Each bogie has three individually-driven, powered axles (i.e., via traction motors).
- **Bo' Bo' + 2' 2' + 2' 2'** multiple unit, first unit: two bogies, each bogie has two individually-driven powered axles; second and third unit: two bogies, each bogie with two non-powered axles.
- **Bo' 2' Bo'** articulated vehicle: first and last bogie have two individually-driven powered axles / middle bogie (Jacobs design) with two non-powered axles.



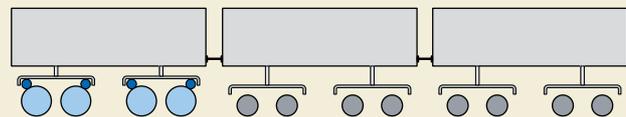
B' B'



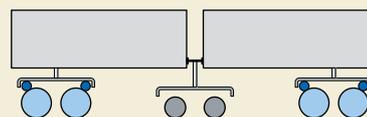
Bo' Bo'



Co' Co'



Bo' Bo' + 2' 2' + 2' 2'



Bo' 2' Bo'

- Motor
- Powered wheelset
- Un-powered wheelset

Wheelset arrangement examples

Wheelset designs

Railway gauge

The gauge is the distance between the two wheel flanges, corresponding to the distance between the inner sides of the rails.

Examples of widely used railway gauges:

- standard gauge 1 435 mm (4 ft. 8 1/2 in.), comprises around 60% of total world track length
- broad gauges, which are larger than standard gauge e.g. Russian broad gauge 1 520 mm (17%), Indian broad gauge 1 665 mm (5 ft. 6 in.) and Iberian broad gauge 1 668 mm (5 ft. 5 2/3 in.), together comprise 9% of total world track length
- narrow gauges, which are smaller than standard gauge e.g. Meter gauge 1 000 mm (7%) and 1 067 mm (3 ft. 6 in.) Cape gauge, comprise 9% of total world track length

Bogie designs for the standard gauge are in some cases adapted for broad gauge vehicles and vice versa. Standard gauge bogie designs can be used in some cases as a basis for redesigning it for narrow gauge vehicles, which then have to be mostly equipped with other bearing designs.

Axleload

The permissible axleload is determined by bridges, roadbed and track design, such as load carrying capacity / weight of the rails, size and frequency of the sleepers, quantity and type of ballast, and depth of formation. On sharp curves, the frequency of sleepers often needs to be increased.

Common axleloads are:

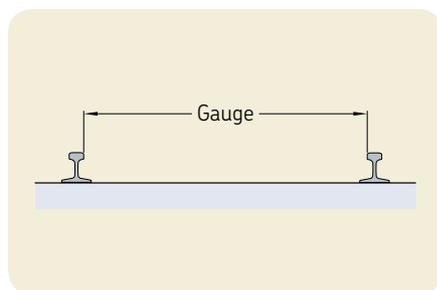
- light metros: 14 t
- high-speed vehicles: 17 t (for new generations)
- heavy metros and multiple units: 18 t
- locomotives and freight cars: up to 25 t
- heavy haul freight cars: 32 t up to 40 t

The axleload is calculated by:

$$\text{Axleload} = \frac{\text{Vehicle weight} + \text{cargo or passenger load}}{\text{Number of axles}}$$

The vehicle net weight includes the operating supplies like sand and for diesel powered vehicles a fully fuelled tank. The cargo refers to the payload of goods. The passenger load can be calculated by counting the number of seats plus, especially for mass transit vehicles, the number of standing persons. There are very different calculations applied, from 4 to 10 persons per m² and 70 or 80 kg average weight per person (with/without luggage) see prEN 15663:2007 Railway applications – Vehicle Mass definition. Further calculation methods are mentioned in specific standards and in customer specifications as well.

Multiple units and articulated vehicles are designed mostly by applying powered and non-powered bogies. Different axleloads have to be considered.



Railway gauge measurement principle

Wheel diameter

Different wheel diameters are considered such as for new wheels, worn wheels or a medium dimension for half-worn wheels. This wheel diameter is mostly used for calculating the bearing rating life, which is a linear function of the wheel diameter. However, the wheel diameter influences the impact of dynamic forces acting on the axlebox bearings, especially by applying smaller wheels.

Some examples of current wheel diameters:

- high-speed vehicles, multiple units and passenger coaches: 750 to 950 mm
- locomotives: 1 000 to 1 300 mm
- freight cars: 900 to 1 000 mm
- piggyback wagons: 350 to 450 mm (carrying trailers, semi-trailers or containers – intermodal freight transport)

Wheelset arrangements

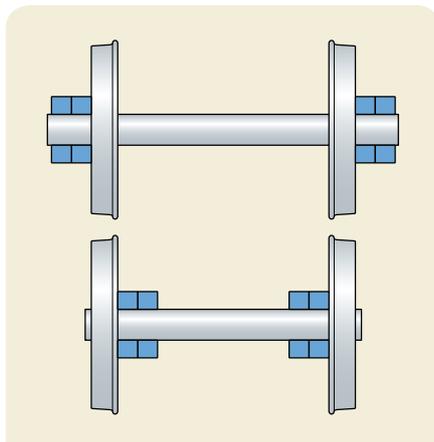
In most cases, axlebox housings are situated on the axle ends. Some vehicles, such as light rail vehicles, have inboard axleboxes that are situated between the wheels because of space limitations. Inboard bearing bogie designs have a potential for mass saving opportunities.

However, there are a few applications where special axlebox bearing designs are needed. The dynamic forces acting on an inboard axlebox bearing can be heavier compared to outboard applications. The smaller support base of inboard bogie frames could cause more rolling of the vehicle body.

Independent wheels

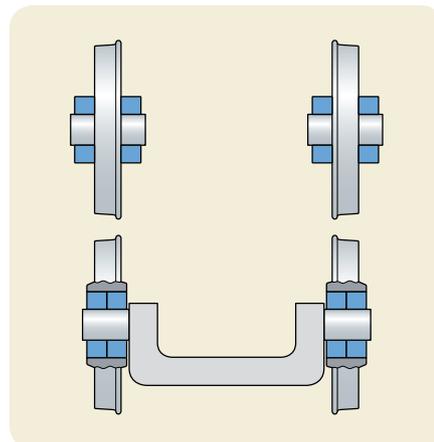
Low-floor mass transit vehicles like tramways are equipped with special wheel arrangements to cope with limited available space. One design principle is the axlebridge design, which consists of a highly sophisticated cranked bridge covering the traditional axle function and two independent wheels fitted with the axlebox bearing units (→ **page 58**).

The hub traction motor concept is based on a direct drive system with an integrated wheel function. Today, very different design principles are applied. One of these is a traction motor design that directly powers the wheel and acts as wheel support and guidance without any gearbox or coupling components. The outside rotor directly powers the rubber spring-suspended wheel tyre. This space saving arrangement is especially suitable for 100% low-floor tramways, which have a plain floor without any steps or ramps.

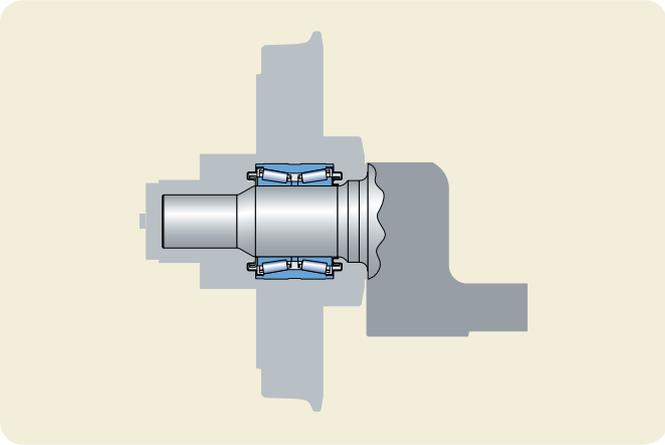


Wheelset design principles

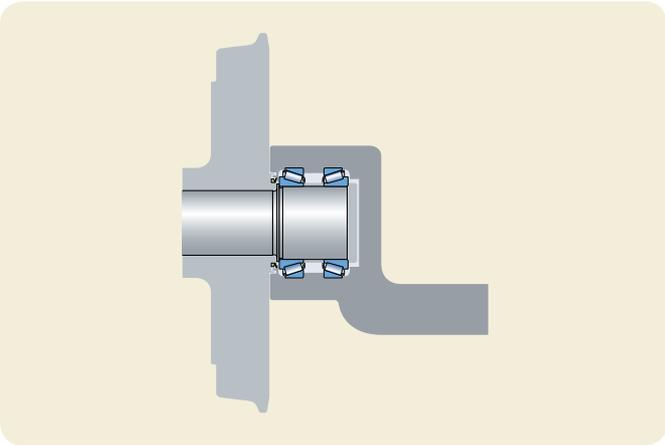
Top: outboard bearing arrangement
Bottom: inboard bearing arrangement



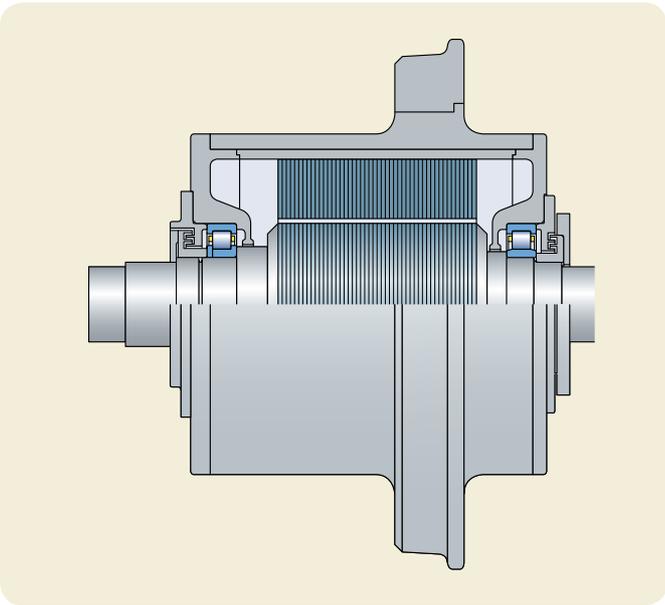
Top: independent wheel arrangement with bearings on both sides
Bottom: Axlebridge design principle



Axlebridge wheel arrangement,
tapered roller bearing unit, outer ring rotation



Single wheel arrangement,
set of tapered roller bearings, inner ring rotation



Hub motor drive system,
supporting cylindrical roller bearings, outer ring rotation

Springs

Primary springs

The primary springs connect the axlebox to the bogie frame. For higher speeds, a secondary spring system connects the bogie frame to the vehicle body. The springs can be designed as steel leaf or coil springs, as rubber springs or as air springs.

The aim of bogie springs is to reduce the forces and vibrations, to avoid derailment and to uncouple vibration and noise between the wheelsets and the vehicle body. The primary spring acts between the wheelset via the axlebox bearing and the bogie frame. The secondary spring is situated between the bogie frame and the vehicle body.

Primary springs acting on the axlebox react to vertical jounce and loads that arise longitudinally and laterally from the influence of the rail track on the vehicle body. In addition, springs decouple structure-borne noise. Enhanced bogie designs are based on different spring systems acting in several directions and using materials such as steel and rubber.



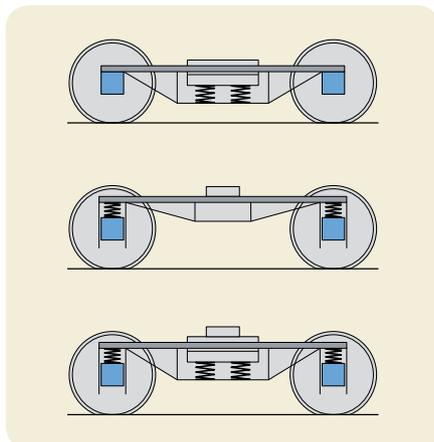
Primary spring system based on steel and rubber springs acting in different directions
Illustration: ContiTech

Secondary springs

Secondary spring systems of enhanced bogie designs are a combination of air spring bellows and the rubber-metal bearer spring, which supports the system, especially when there is torsional strain and large horizontal excursions. The system also absorbs a portion of the vertical deflection and acts as an emergency spring. An additional feature of air springs is the constant levelling function that maintains the vehicle body at a consistent height, regardless of whether it is full of passengers or empty.



Secondary spring system based on an air spring system combined with rubber springs
Illustration: ContiTech



Spring principles:

Top: mainly used for freight cars

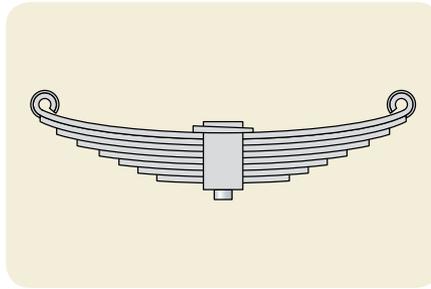
Middle: mainly used for freight cars and powered vehicles

Bottom: mainly used for passenger coaches, multiple units and locomotives

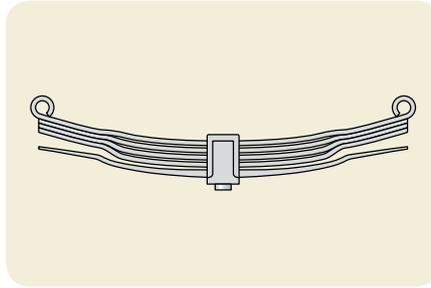
Steel spring design principles

Steel springs are used for the majority of all railway vehicle types. There are several designs applied, such as:

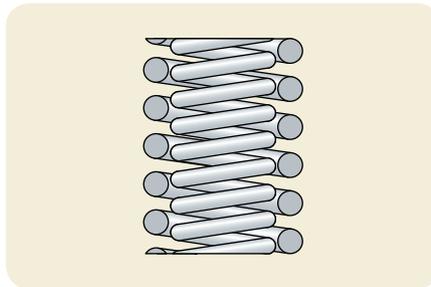
- Leaf type springs have a linear characteristic and a mechanical damping effect between the leaves. Most of the leaf type springs are acting on top of the axlebox.
- The parabolic leaf type spring has a multistep characteristic as well as a mechanical damping effect between the leaves. These springs act mainly on top of the axlebox.
- Cylindrical helical springs are made from round coils. They are also used as a spring interlaced set with progressive characteristics, which is achievable by using different spring heights and leads. These springs can act either on top of the axlebox or on both sides.
- Another design modification is the flexi-coil cylindrical helical spring arrangement. The flexi-coil effect is used to combine the spring function and the guidance of the bogie frame. The vehicle body is able to move laterally relative to the bogie against the restoring force of the springs. This spring design is widely used for locomotives.



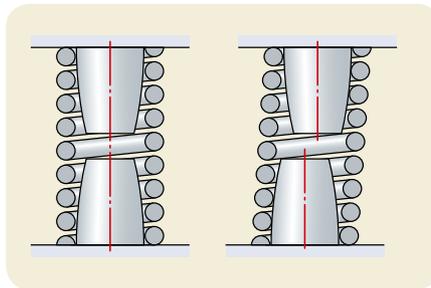
Leaf type spring



Parabolic leaf type spring



Cylindrical helical spring



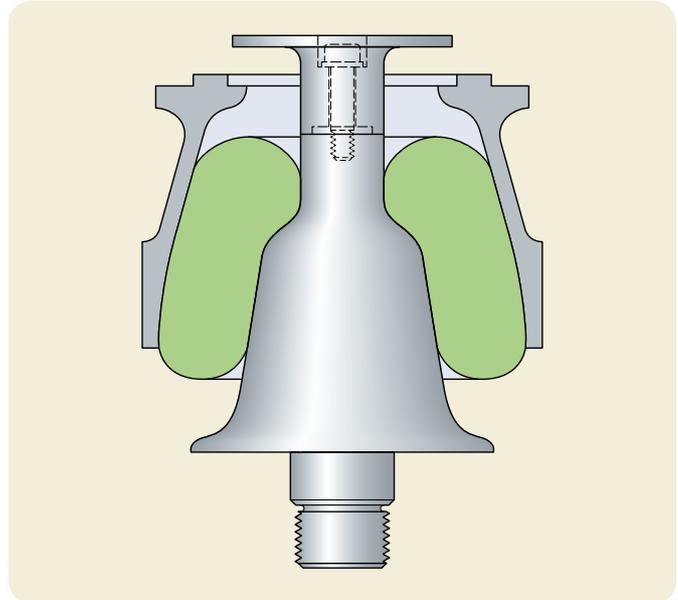
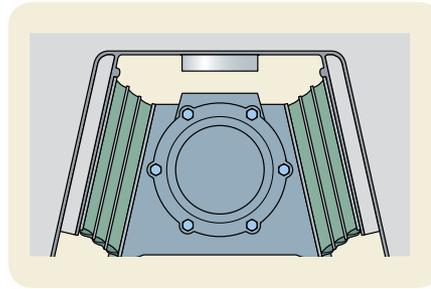
Flexi-coil spring arrangement

Rubber spring design principles

An alternative to steel springs are rubber springs, which offer a larger design flexibility in regard to geometrical shape and material selection. Some of the main rubber spring designs are:

- Chevron springs are made from rubber metal compounds and have a progressive characteristic as well as a damping effect. They are typically acting on both angled supports of the axlebox.
- Clouth springs are based on a rubber ring rolling on a cone that can have a tailored profile to achieve a specific characteristic. Clouth springs also have a damping effect. These springs typically act on both sides of the axlebox and, in addition, fulfil the guiding function of the wheelset [7].
- Other rubber spring design principles are hollow block springs, hollow block layer springs and conic rubber springs.

Chevron spring



Clouth spring



Other rubber spring designs:

*Left: Hollow block spring
Middle: Hollow block layer spring
Right: Conic rubber spring
Illustration: ContiTech*

Dampers

In addition to the self-damping effect of some of the spring designs, additional dampers are used. These dampers are mainly designed as hydraulic dampers acting on the axlebox in different directions.

One damper design example is the twin-tube hydraulic damper. This device holds the wheelset on the bogie and the bogie on the rail. On both ends, either rubber elements or plain bearings are fitted. One end is typically connected with the axlebox.

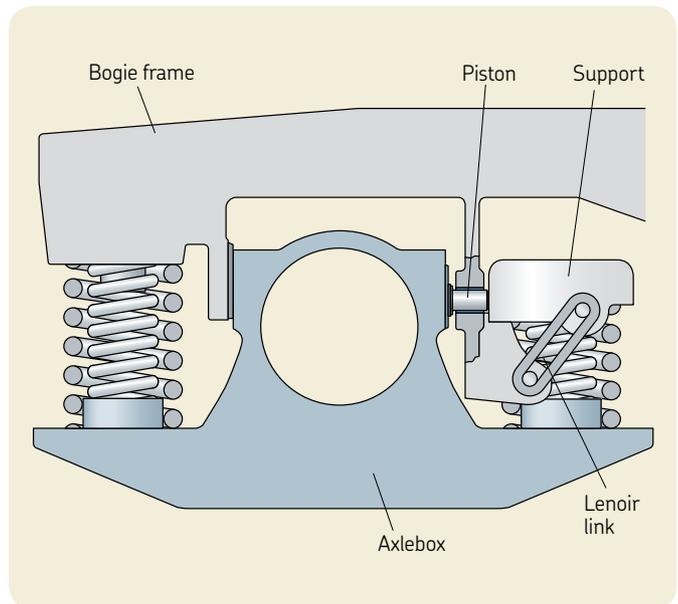
In addition to hydraulic dampers, mechanical damper designs are applied. For Y25 freight cars that are mainly used in Europe, mechanical Lenoir friction dampers are used. The guiding surface of the damper acts on the guiding surface of the axlebox housing.

Active damping

The active damping system controls resistance against motion of the vehicle body. This system helps to provide a more convenient and comfortable ride on trains.



Twin-tube hydraulic damper
Photo: ZF Sachs AG

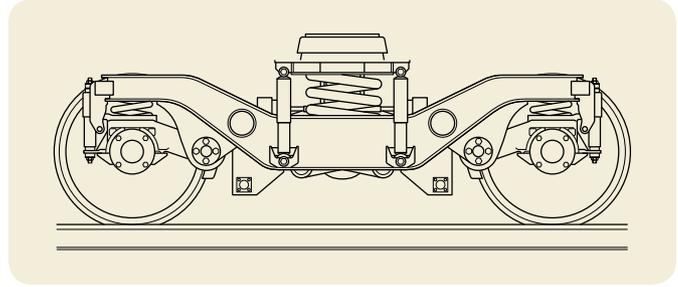


Lenoir friction damper

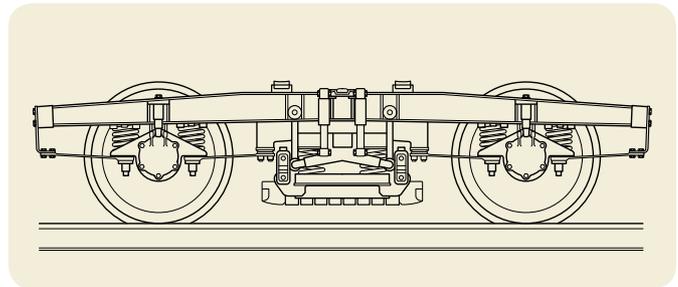
Bogie design examples

There have been many different bogie design principles applied throughout railway history. Even today, for the latest state of the art rolling stock, different design principles are still in use. In this chapter, some current bogie design principles are mentioned to give an overview of bogie design technology and their interaction with the axlebox design [8, 9, 10]. The aim of this chapter is to focus on guiding/suspension and primary spring and damping design that influence the design of axleboxes and bearings. The axlebox design features are mentioned in **chapter 3**.

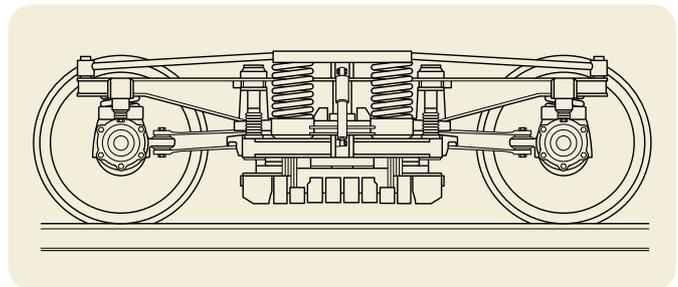
High-speed, passenger coach and multiple unit bogies



Link arm suspension with one primary helical spring on top of the axlebox assembly, which is designed as a yoke, enabling vertical dismounting of the wheelset assembled with the axlebox for easier maintenance. This design was applied for the French bogie type Y32 for Corail coaches and is similar to Italian bogie Fiat Y0270S and Spanish bogie CAF-GC. 1 and is widely used in Europe, for instance in the Alstom TVG bogies.



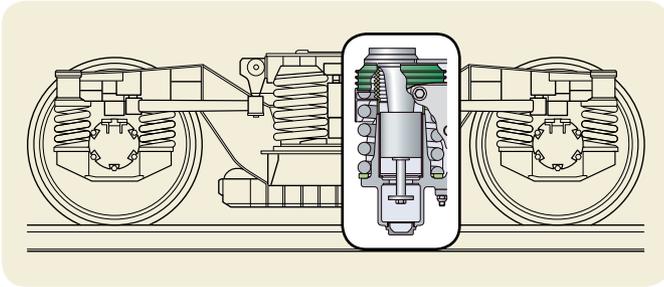
Suspension by two steel leaf springs acting on both sides of the axlebox housing, which is equipped with two helical springs. This design is known as Minden-Deutz bogie MD 36.



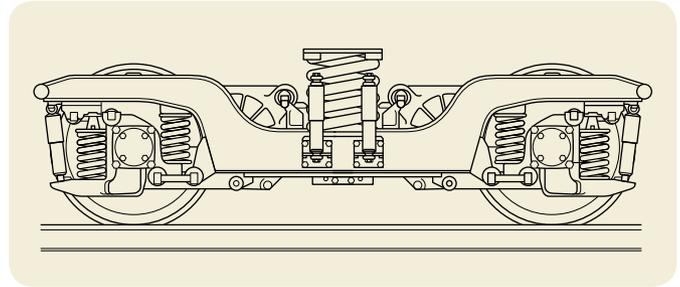
Suspension by two parallel steel leaf springs acting on one side of the axlebox housing, which is equipped with helical springs. Axlebox assembly designed as a yoke, enabling vertical dismounting of the wheelset assembled with the axlebox for easier maintenance. Originally known as Minden-Deutz MD 52 bogie, it was later used for the MD 522 design, which used in the German ICE trailer bogies.

Locomotive bogies

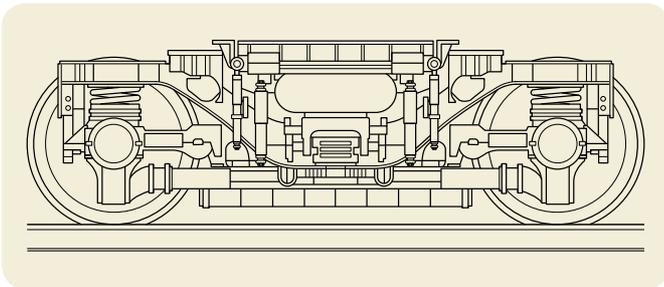
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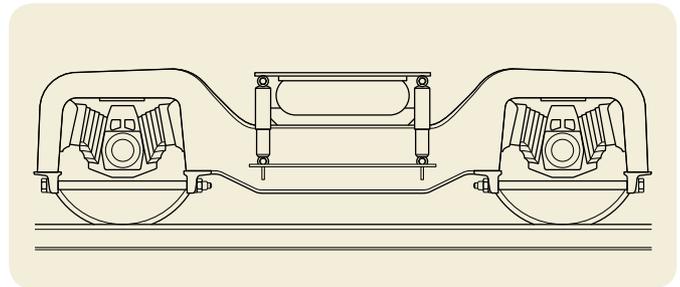
The cylindrical guidance system is acting on both sides of the axlebox and has an integrated damping function. In addition, helical steel springs are applied. This design is used for passenger coach bogies like SGP 300 and Siemens SF 300.



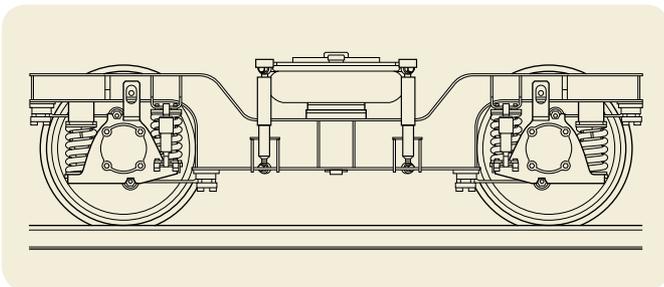
Suspension by two diagonal link arms supported by the axlebox. Two helical steel springs on both sides. This bogie design is used by different suppliers like Alstom.



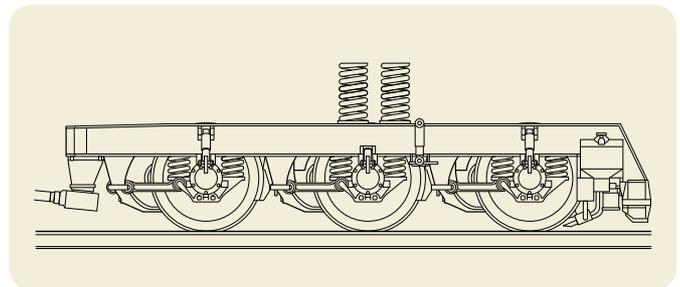
Suspension by a moving motion link as an integral part of the axlebox. The primary helical steel spring acts on top of the axlebox. This design is used, e.g. in the German ICE 3 bogies and build as SGP 500 or Siemens SF 500.



Suspension with inclined side supports for Chevron rubber springs, acting as suspension and guidance, adaptable to different spring characteristics. This bogie design is used for various locomotives, multiple units and mass transit vehicles as well as for Swedish X2000 high-speed tilting trains.



Suspension by a steel leaf spring acting on one side of the axlebox housing, which is equipped with two helical springs. This design principle is used by several bogie manufacturers like MAN, ADtranz, Rotem etc.



Flexicoil suspension springs are acting on both sides of the axlebox. Additional horizontal guidance via link arms connecting the axlebox with the bogie frame is applied to transmit the longitudinal tractive and brake forces. This locomotive bogie design principle is used by ADtranz today Bombardier for different bogies based on 2- and 3-axle designs.

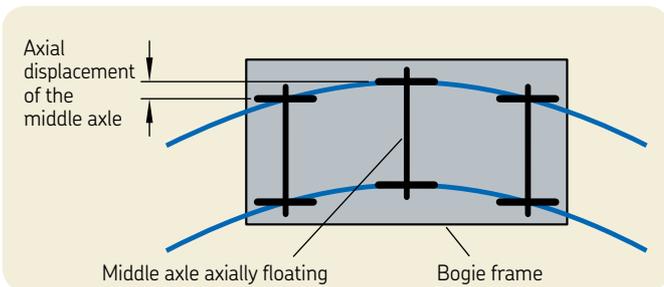
3-axle locomotive bogie designs

Early middle axle wheelset designs were based on wheels with smaller or even no flanges e.g. for shunting locomotives or steam locomotives with more axles. Today, there are two principal solutions to manage the axial displacement of the wheelset of the middle axle:

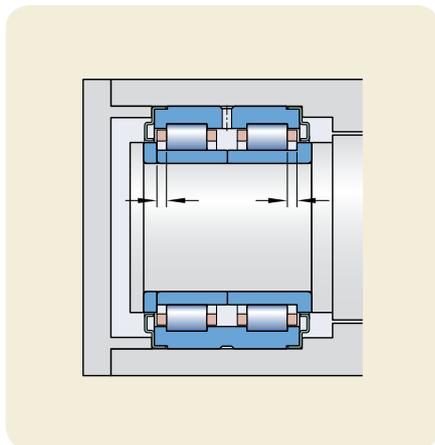
- axleboxes of the middle axle axially floating in the bogie frame, e.g. axial elastic support
- axleboxes of the middle axle equipped with a special bearing system with axial floating capability

Special cylindrical roller bearing units for axial displacement are mentioned on **page 95**.

The 3-axle bogie design requires a special lateral movement of the middle axle by running curved tracks.



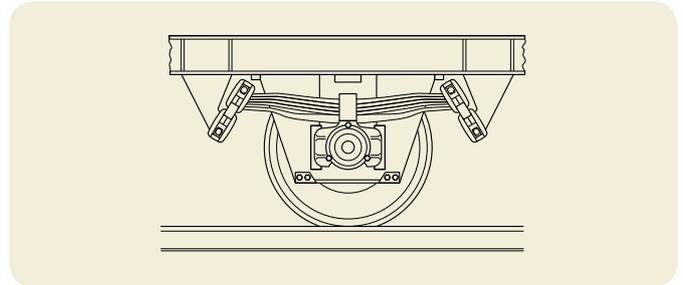
Bearing unit design principle for middle axle applications of the 3-axle bogies



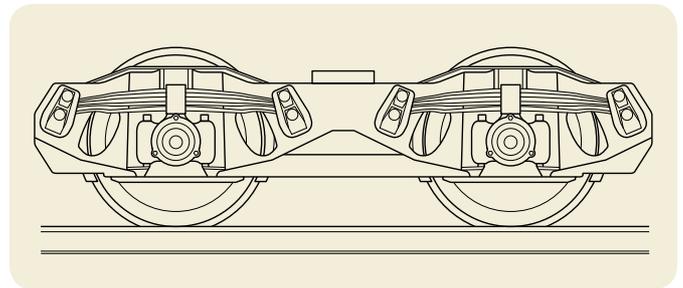
Freight car bogie designs

European freight cars

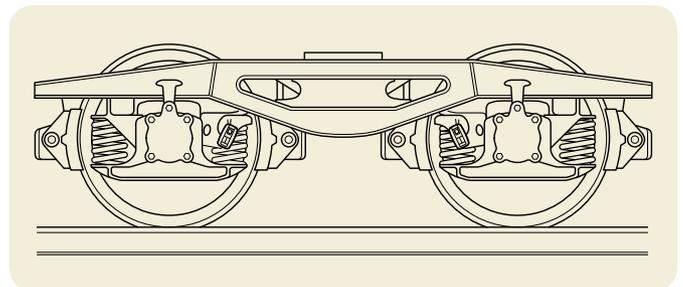
European freight car designs are based on bogie designs as well as 2-axle running gears. These designs are also used in other parts of the world like in Asia.



Steel leaf spring suspension typically used for 2-axle freight wagons. The spring acts on top of the axlebox and guides the wheelset. The large longitudinal gap between horn guides enables a radial self-steering effect.



Parabolic steel leaf spring suspension typically used for freight bogies. The spring acts on top of the axlebox and guides the wheelset. The large gap between horn guides enables a radial self-steering effect. This design is used e.g. for the German 665 bogies.



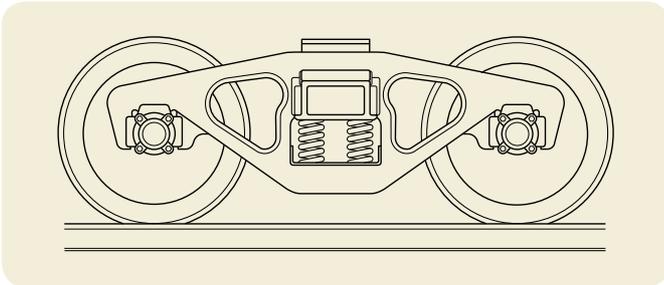
Suspension by horn liner guides. Two helical steel springs acting on both sides of the axlebox. Damping by a Lenoir friction damper (→ page 35). This design is known as UIC bogie type Y25, which can be manufactured as cast or fabricated side frames.

3-piece bogie designs

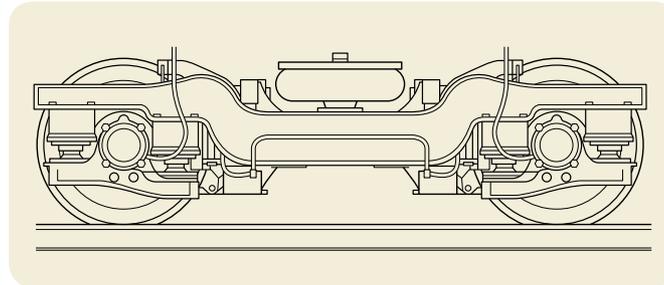
The 3-piece bogie design was originally developed in the USA and is used worldwide. It consists of two longitudinal beams and a connecting beam. The bearing system is directly fixed with the longitudinal beam without a primary spring. The secondary spring is integrated into the transversal beam design. This design principle is also used widely in China and Russia.

Mass transit bogies

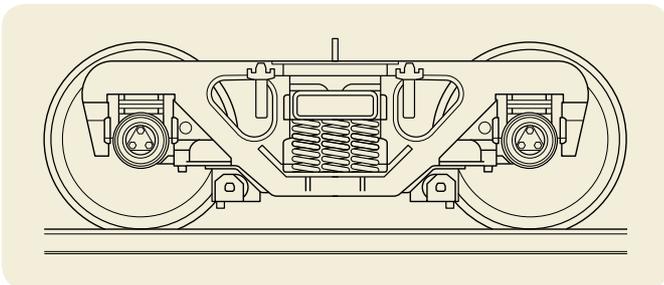
Mass transit vehicles, such as suburban trains, metro cars, light rail vehicles and tramways, can be principally divided into standard height floor cars and low-floor cars. The set-up heavily influences the design of the bogie.



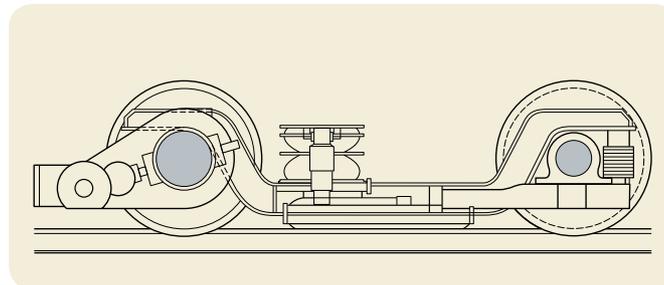
Sealed and greased axlebox bearing unit, directly fitted via an adapter with the transversal bogie beam without any primary suspension. This freight car bogie design is standardized, the AAR using narrow and wide adapters and different bearing sizes.



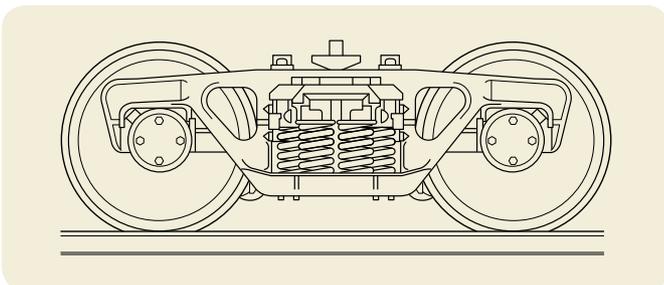
Rubber guidance and spring load by applying different types of rubber springs acting on both sides of the axlebox. This design is applied by several bogie manufacturers, e.g. for Siemens SF 1000 bogies for light metros with an axleload of 14 t and SF 3000 bogies for heavy metros for up to 17 t axleload.



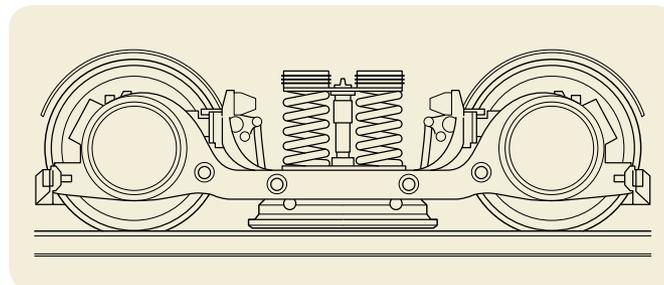
Sealed and greased axlebox bearing unit, directly fitted via an adapter with the transversal bogie beam. A rubber blanket is used as primary suspension between the adapter and the suspension. This freight car bogie design is used by Chinese railways.



Low-floor bogie with axleboxes integrated into a link arm bogie design element. This design, using an independent wheel design, is used for light rail vehicles and tramcars and was originally developed by MAN and is now finally used by Bombardier after several acquisitions. The powered wheel pair (left side) is loaded 2/3 and the non-powered around 1/3 of the total bogie load.



Axlebox directly fitted via an adapter with the transversal bogie beam. The adapter is equipped with a front cover to protect the bearing system. This freight car bogie design is used by Russian railways.

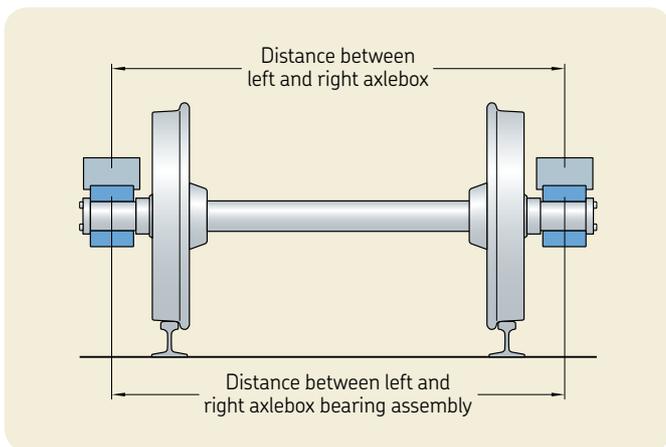


The moving motion link supports the drive system unit consisting of a planetary gearbox and a traction motor. The motion link is spring loaded via a longitudinal primary rubber spring. This design is used for Bombardier Cityrunner low-floor tramways.

Axial tolerances

To make sure that the axlebox bearing is not distorted axially by improper fastening, several tolerances have to be considered by the bogie manufacturer:

- axial tolerance of the guidance's acting on the axlebox
- axial tolerance of the axial bearing surface of the wheelset
- axial tolerance of the bearing inner/outer ring assembly width and the attachment parts, such as backing ring or labyrinth ring



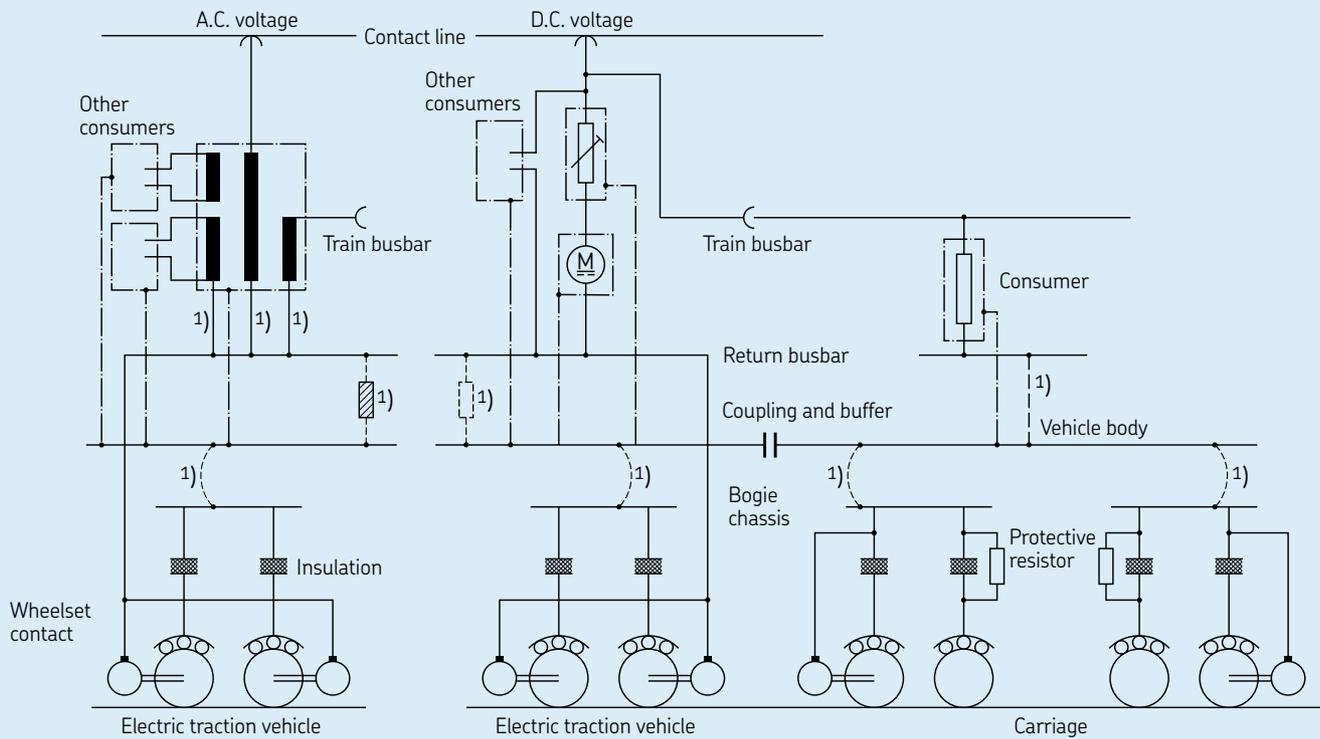
Axial tolerance principle

Earth return

The problem of electric current passing through rolling bearings like axlebox bearings and causing damage in the contact area of rollers and inner/outer ring raceways is well-known. In addition to the damage to bearing elements, it was also assumed that the structure of the lubricant itself might change under the influence of a passing current. All axlebox bearings potentially suffer from this phenomenon. Craters are formed and are known as electric pitting. In a more progressed stage, fluting or washboard pattern of multiple grey lines across the raceways can be detected (→ page 131).

Earth return devices transmit electrical current from the stationary part to the rotating axle of the wheelset. These devices avoid dangerous voltages between the vehicle and the ground as well as avoid damage to axlebox bearings by passing electric current through raceways of bearing rings and rollers. The earth return acts as a low ohmic bridge that transmits the current with coal brushes to a rotating part. The maximum current is in the range of 1 000 A, depending on the earth return design. In the German standard, DIN VDE 0123, electrical current flows in railway vehicles are explained in detail and suggestions to avoid current passing through axlebox bearings are proposed.

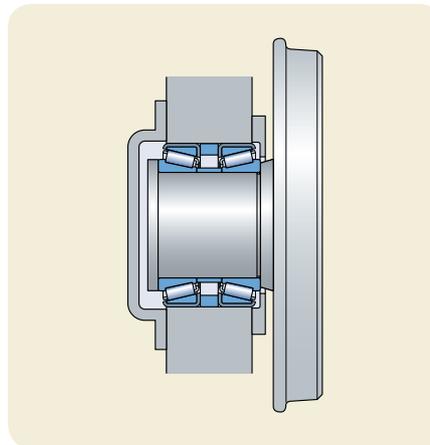
A sufficient earth return design is a prerequisite to reach the requested reliability and safety requirements on axlebox bearings. However, the correct selection of the coal composite material and the minimization of the responding coal wear is very fundamental. The earth brush design has to avoid wear particles entering the bearing system and affecting the lubrication and contacting surfaces between rolling elements and inner/outer rings.



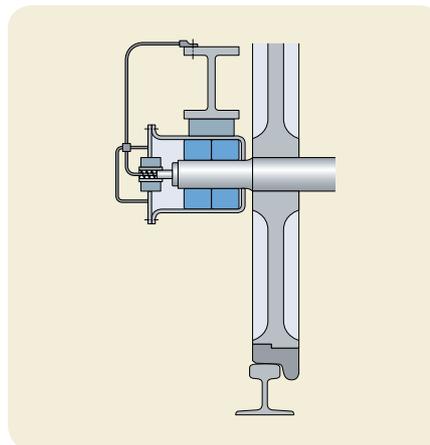
1) Connections in accordance with DIN VDE 0115 Part 2

Electric current flow in railway vehicles: combination of insulation, earth return devices and protective resistors (example)
 Source: DIN VDE 0123

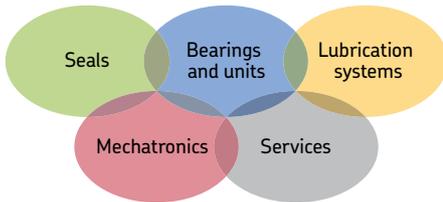
One option to insulating axlebox bearing arrangements is to use the electrical insulated SKF INSOCCOAT bearings [11, 12]. The insulating coating on the outer ring of the INSOCCOAT bearing is made from aluminium oxide and applied using plasma spraying technology. This execution is widely used for electric traction motors and there are also some applications, e.g. for low-floor tram cars, that are equipped with INSOCCOAT as well. The bearings are interchangeable with non-insulated bearing types because of ISO standardized boundary dimensions and tolerances. This INSOCCOAT design prevents passage of damaging electric current through the bearings.



Electric insulated INSOCCOAT bearing arrangement for low-floor light rail vehicles



Earth return device in combination with insulation of the axlebox



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