OPTIMAL DESIGN OF LOW-FLOOR TRAM

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Introduction

The main requirements for modern trams were set at 2nd UIPT Conference which held in September 1994 in Amsterdam. The requirements are following:

- Operators require from the producers a low purchase cost of vehicles, low-cost maintenance and above all an application of reliable modern technology (regeneration of the braking energy, asynchronous motors, anti-skid and anti-slip wheel control, and diagnostics). Then they also require attractive design, comfortable seats with anti-vandalism protection, low noise level, sufficient ventilation and heating (possibly air-condition), understandable information system and high-level safety of operation.
- Passengers require cheap fares, reliability, easy getting-on and getting-out the vehicle, regularity of the service with short intervals, high accessibility with a low number of changing.

Optimal design concept of low-floor tram is also highly dependent on required service and technical conditions under which the vehicle should operate. These requirements may vary, thus the producers tend to use modular design of articulated trams in order to reach the lowest possible price. According to the percentage of the low floor, the trams can be divided into two main categories:

- **Partially low-floor trams** – with the ratio of low floor at least 50% of the total length of the floor. The height of the low floor is about 350 mm above the top of rail. The height of the high floor is usually 560 – 600 mm above the top of rail.
- **Fully low-floor trams** – whole floor is at the low level, approx. 350 mm above the top of rail. But above the bogies the floor can be a bit higher (up to 450 mm above the top of rail)

Configurations of low-floor trams of the main concepts

Partially low-floor trams

All the partially low-floor trams are using standard traction bogies that are situated under the end sections. These are two axle bogies with crosswise oriented suspended motors and they can pivot along their vertical axis up to 15^0. The radius of the wheels is usually small – about 590 mm. Because of the pivoting of the bogie the floor above it must be at the high level.

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In the place between the standard bogies there is the low-floor. Steps or ramps can be between the two levels of the floor in the passenger compartments. Then there are two main design concepts of partially low-floor rams:

Trams with two axle or single axle running bogies – that are three-section low-floor trams with long sections. As already mentioned, under each end section there is one standard bogie. The floor level above them is high. Under the centre section there are two running bogies at the ends of the section. These bogies can be either two axle or single axle type. The two axle bogie is pivoting along its vertical axis but the wheelset base is small - about 1.2 m. The radius of the wheels of these bogies is also smaller – about 450 mm. These six-axle or eight-axle low-floor trams have got the wheel arrangement $B'_0\,\overline{1'}\,\overline{1'}\,B'_0$ or $B'_0\,\overline{2'}\,\overline{2'}\,B'_0$ and are suitable for tracks without steep gradients and without a large number of curves of small radius. The disadvantage of this concept is the need of using two different types of bogies in one vehicle – standard traction bogies and running bogies. Thus only 50% – 70% of the weight of the vehicle is used for accelerating (the vehicle is not of 100% adhesion).

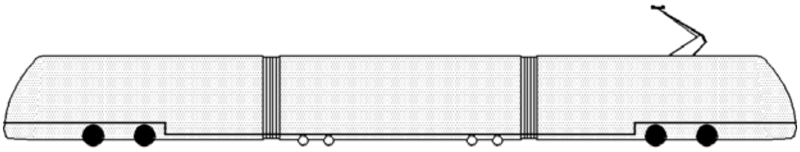


Fig. 1 – Partially low-floor tram with two axle running bogies

Trams with short carbody sections – under the long end sections are - similarly as in the previous category – the standard traction bogies. Between the long end sections there is one short section (in a case of six-axle vehicle) or two short sections which are connected to each other with another long section (in a case of eight-axle vehicle), Fig. 5. Under the short section there is a running or traction bogie which cannot pivot along the vertical axis. These bogies are of axles design with independent wheels. Due to this design of the bogies there can be the low floor situated above them. The ratio of the low floor is up to 70% of the total length of the floor. The wheel arrangement is $B'_o\,\overline{B'_o}\,\overline{2'}\,B'_o$ or $B'_o\,\overline{B'_o}\,\overline{B'_o}\,B'_o$, so it is possible to have 100% adhesion vehicle. The disadvantage of this concept is again the need of two different types of bogies – the outer standard bogies and “low-floor” bogies that are placed under the short sections.

Fully low-floor trams

All the main concepts of fully low-floor trams are using the axles bogies with independent wheels and without pivoting. There are two main concepts:

Trams with long carbody sections of the same length – under the sections in the middle there is a “low-floor” bogie which cannot pivot along its vertical axis and with independent wheels. Due to the not pivoting bogies under quite long sections the running behavior of the vehicles of this concept is not very good.

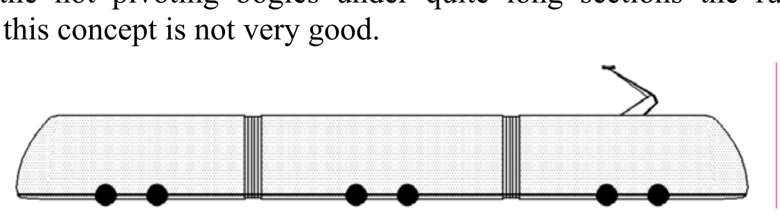


Fig. 2 – Fully low-floor tram with long carbody sections of the same length

Trams with short carbody sections and suspended long sections – these vehicles are similar as the partially low-floor trams with short carbody sections. Only the end sections are divided into two sections each and all the bogies in the vehicle are of the same design – “low floor" bogies which were already described. The running behavior of these vehicles is better then of the vehicles of the previous concept. But still due to the not pivoting bogies these vehicles are not suitable for tracks with a large number of curves of small radius, especially without transition curves.

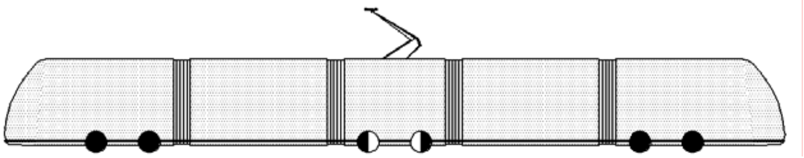


Fig. 3 – Fully low-floor tram with short carbody sections and suspended long sections

In Fig. 4 there is the comparison of Y forces acting on the outer wheel of the first wheelset during the vehicle negotiating the curve of small radius without transition curves (speed 15 km/h, curve radius 20 m). There are vehicles of two concepts compared – partially low-floor tram with short sections and fully low-floor tram with short sections. When entering the curve there is a great rise of Y force in a case of fully low-floor tram which is caused by not pivoting bogies under the end section. Later when the first bogie already entered the curve the Y force drops down at approx. the same value as in a case of partially low-floor tram with pivoting outer bogies. Due to this fact the fully low-floor trams are more likely to derail and have to run at a low speed when entering the curve.

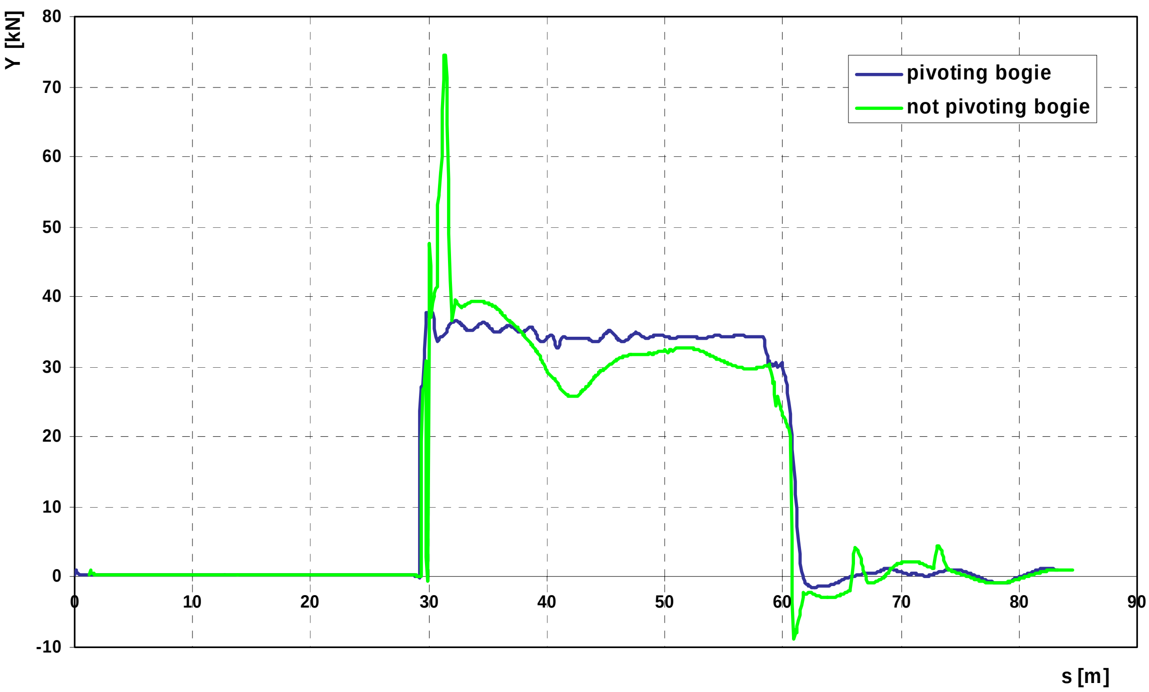


Fig. 4 – Y forces on the outer wheel, first wheelset, speed 15 km/h, curve radius 20 m

Optimal design of low-floor tram for Prague

The tram track in Prague is characterized by steeper gradients and a high number of curves of small radius without transition curves. This leads to the vehicle with at least the outer bogies pivoting and all the wheelsets should be driven (100% adhesion vehicle).

From the described main design concepts of low-floor trams the most suitable concept for Prague is the concept of partially low-floor tram with short carbody sections. This articulated tram can be three-section six-axle or five-section eight-axle (Fig. 5).

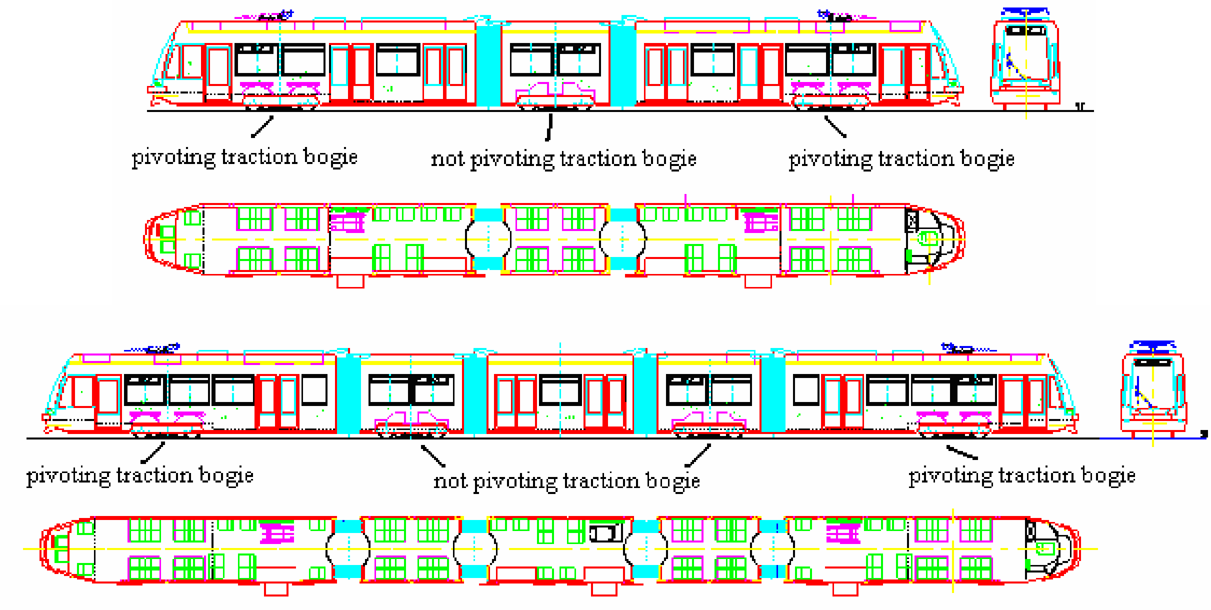
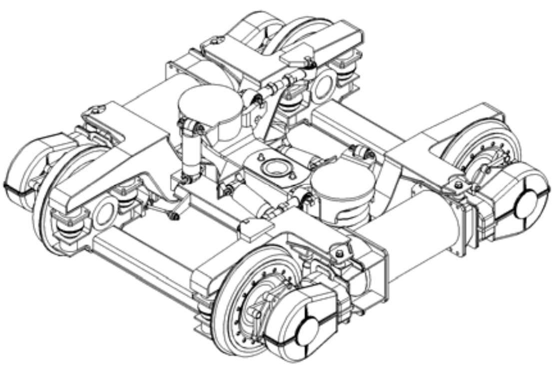
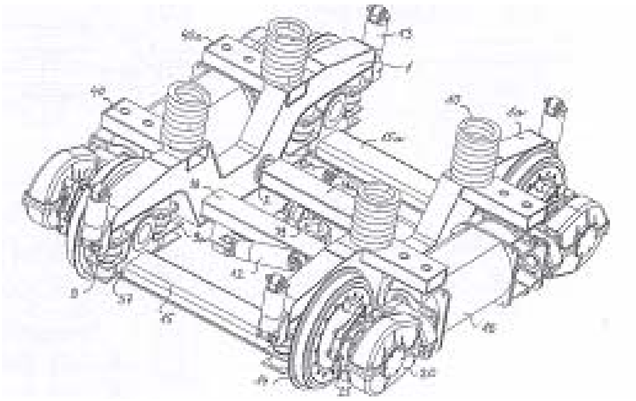


Fig. 5 – Six-axle and eight-axle low-floor trams with short sections

As mentioned, the disadvantage of this vehicle is the using of two types of bogies in one vehicle – the outer standard bogie with wheelsets and the "low-floor" bogie with independent wheels. For eliminating this disadvantage the following bogies could be used (Fig. 6):



Pivoting traction bogie (O.Č. 16 360 CZ)



Not pivoting traction bogie (Patent CZ 286660)

Fig. 6 – Drive bogies for low-floor trams

On the left side of the figure there is a pivoting bogie that can be used under the end sections. On the right side there is a bogie that can be used under the short center sections and which allows placing of the low floor above it. From the pictures it's obvious that the main components are for both bogies the same (independent wheels, bogie frame, drive unit, primary suspension). The drive units are suspended on the sides of the bogie frame, each asynchronous motor drives the two wheels at each side. The primary suspension is realized by rubber-metal elements. The only difference between the bogies is in the secondary suspension. This is realized in a case of not pivoting bogie by four coil springs that are connected directly to the bogie frame. In a case of the other bogie the coil springs are situated in the central part of the bogie and they are connected to the bolster. The bolster is then connected through a bearing to the car body and enables the bogie to pivot along its vertical axis.