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Ultralight drive systems structures of freight wagons – Possibilities and limitations resulting from regulations

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ABSTRACT

The article presents issues related to current development trends in rail transport of cargo, aimed at implementing ultra-light structures of drive systems of freight wagons. Putting such structures into operation is consistent with the general policy of the countries associated with the European Union, aimed at climate protection. The ultra-light structure achieves this goal for the first time in the production process and for the second time in the transport process, i.e. the energy used in the transport process is used more effectively in the transport processes. In addition, the transport position of rail freight transport on the means of transport market is increasing. The paper presents a comprehensive approach to the subject of construction of running systems of rail vehicles in the context of development possibilities towards optimizing mass and negative impact on the natural environment, taking into account the requirements they must meet. The paper presents comprehensive requirements for individual elements of a freight wagon bogie, taking into account all technical, standard and operational aspects essential for obtaining the correct design of the bogie.

Keywords: running gear, freight cars, low net weight, construction.

INTRODUCTION

Modern rail cargo transport is under increasing pressure from tough market competition. In order to cope with it, it is necessary to implement new solutions that will increase the reliability and availability of such transport. The opportunities for rail freight transport increased when, in accordance with Europe an Union directives, the rail infrastructure of Europe an countries was made available for international traffic [1]. Therefore, the most important direction in the development of railroad car construction is the transition to such economic and progressive structures that meet the modern requirements of the transport services market [8]. Lightweight design solutions often come at high costs [13].

The railway system is complex. The dynamic response of a freight wagon strongly depends on the interaction between vehicle and track respectively vehicle and the transported goods. Main requirements for the technology used in freight transport systems are safety and cost efficiency. Due to the complexity with various conditions in different countries an introduction of new types of running gear or enhancement in operational conditions, i.e. increased axleload and speed, has to be made with great caution. The running gear on freight wagons used in international traffic have great uniformity [9].

The article is a summary of analyzes of development trends aimed at achieving the minimum unladen vehicle weight in terms of design, taking into account operational, functional, environmental, technological and driving safety requirements. The analysis was carried out for standard drive systems of freight wagons based on the Y25 bogie structure. By achieving the above objectives, the transport potential of individual freight wagons increases, which will increase the attractiveness of rail transport on the freight transport market. The problem of limiting the tare weight is a design, technological and operational issue.

The bogie should be universal, interchangeable with the bogies existing in operation according to installation dimensions and standardized to the maximum level according to the components. It should be not only simple in design, but also in manufacturing (to ensure minimum production costs and technical maintenance of such bogies). Their operation should be costeffective [10].

The aim of the article iLightweight design or design for function and mass is becoming increasingly important. There are a number of different causes for this. Reducing the mass of a product can reduce energy consumption and CO_2 emissions. This can lead to the improved economic and ecological performance of the product, for example, in the case of vehicles. Also, by reducing mass, acceleration times can be shortened, for example, in the case of industrial robots. In addition to the reduction of mass, optimisation of the distribution of mass can reduce the physical forces and moments resulting from the mass of the product and thus the physical impact on the user can be reduced. Optimisation of the distribution of mass can also result in better dynamic properties of the product, such as for example higher possible cornering speeds in the case of vehicles. As a result of the distribution of mass, the mass moment of inertia of the product can also be influenced. Optimisation of the mass moment of inertia again has an influence on the acceleration time, which can be reduced by optimizing this moment. The reverse shows that holistic designing for function and mass means respecting mass as an optimisation criterion as well as respecting the distribution of mass and the resulting mass moment of inertia.s to present the possibilities and limitations resulting from the specificity of railways [12].

The direction of reducing the weight of the running gear seems to be correct from a technical point of view, but it must lead to a design that works well in commercial operation, which is characterized by increasingly longer annual kilometers and fewer inspections and repairs P1÷P5

TRENDS IN DEVELOPMENT OF ULTRALIGHT STRUCTURES

Design assumptions of the ultralight running gear

When constructing a new running gear system with reduced weight, the following criteria should be taken into account:

- adapting the design of the running gear system to transfer the forces resulting from the pressure of the wheel set on the track, which is 22.5 t (220 kN)
- adapting the design of the running gear system to the speed of a freight wagon of 100 km/h when loaded and 120 km/h when empty, and in compact trains (for transporting containers, semi-trailers and interchangeable tanks) to a speed of 140 km/h, with the transfer of forces resulting from wheel set load of 18 t (176 kN),
- ensuring the bogie base (distance between the centers of wheel sets) 1800 mm, established by ORE/ERRI/UIC as part of the standardization of European standard gauge running systems
- use of non-alloy structural steel on the bogey's supporting structure, e.g.: S355 J2 K2 according to PN-EN 10025-2:2019-11 [15], meeting the strength requirements according to the European standard PN-EN 13749:2021 [18],
- use of a wagon body resting system, consisting of a spherical socket with a radius of R = 190 mm and a plastic insert according to the ORE/ERRI document No. SVA B12 DT 191 [41], enabling cooperation with the turning pin and spring slides with vertical clearance of 12 ± 1 mm resulting from tests of running properties; the standard resting system on the bogey body allows for dimensional interchangeability with previously used running systems,
- ensuring an appropriate outline of the bogey (the so-called gauge) that meets the requirements of the UIC 510-1 card [31],
- use of a wheelset in accordance with the UIC 510-1 card [31], with a pin Ø130 × 191, with a hub diameter of Ø 200 mm and central axle elements Ø173+2 mm, with a monoblock wheel with a running diameter of Ø920 + 4 in new condition (in accordance with UIC 510-2 card [32]) and with permissible radial wear of 40 mm, made of ER7 steel according to PN-EN 13262:2021 [18] (in the case of a block brake) and ER8 according to PN-EN 13262:2021 [18] (in the case of using a disc brake), the axle of the wheelset should be made of EA1 steel according to PN-EN 12261:2021-02 E [16], while the wheelset should meet the requirements of PN-EN 12260:2021-02E [17],
- use of a bearing housing (axle box) to work with TBU 130 × 240 × 160 bearings,
- the required reference profile of kinematic vehicle gauge which must not be exceeded by the design profile of the running gear

or any part thereof in any actual but normal operating conditions; the running system must comply with the requirements of European standards PN-EN 15273-1+A1:2017E [22], PN-EN 15273-2+A1:2017E [23] and 15273-3+A1:2017E [24],
- ability to operate without disruptions in the required ambient temperature range of -25 °C ÷ 40 °C i.e. in the T1 range according to the PN-EN 50125-1:2014E standard [26] and in unfavourable weather conditions,
- protection of the natural environment in multiple aspects, e.g. protection of the environment from excessive noise emission from driving vehicles, emission of harmful substances into the natural environment (including wear products) and compliance with recycling principles,
- compatibility with railway infrastructure devices for railway traffic control (SRC); this system imposes an external bearing solution, because ASDEK type devices for detecting overheated rolling bearings are placed on the external side of the track in accordance with the appendices of the ORE/ERRI B12.4 report [40],
- ability to pass through a track curve (workshop) with a minimum radius of R = 35 m for the running gear alone; ability to pass should be tested analytically as well as experimentally,
- ability to travel on a track with a longitudinal gradient of 40‰,
- required noise emission level generated when driving, by using LL type brake blocks (in the case of existing freight wagon bogies, LL type blocks [40] have the same dependence properties of the friction coefficient between the wheel running surface and the brake block on speed as GG type blocks), K type blocks [38] (composite with a high coefficient of friction of 0.3 ÷ 0.4 that is unaffected by speed) in newly designed running systems, instead of the previously used ones made of phosphorus cast iron called GG type according to UIC card 832 [35],
- easy operation and inspection of the vehicle technical condition by persons authorized to authorize the freight train to depart,
- collision-free operation of elements in all normal operating conditions, also with those elements that are installed on the wagon body; such operating conditions include the maximum deflection of the bogie in relation to the wagon when passing through track curves of small radii, maximum deflection of the suspension in all wear conditions of the wheel rims (from new to the maximum permissible wear condition),
- sufficient accessibility of elements during repairs (repairability) for the service personnel, in cases when it is not possible to dismantle the pivot-socket system and roll the bogie out from under the wagon, e.g. replacing brake inserts with new ones after reaching the permissible wear,
- high reliability, availability and durability of individual elements with increased mileage,
- compliance with the requirements of the PN-EN 14363+A1:2019 E, P [21] standard and UIC sheet 432 [27]; these regulations require that dynamic properties be met at speeds of 136 km/h (120 km/h + 10%) when empty and 110 km/h (100 km/h + 10%) when loaded; the above requirements can be met by maintaining the equivalent conicity, in accordance with UIC card 519 [34],
- obtaining the smallest possible angles of wheel on rail run, especially when passing through track curves of small radius, i.e. R = 250 m (the smallest radius on track); this is associated with a significant reduction of transverse guiding forces ΣYi and with a reduction in the wear of wheel flanges of wheelsets (the Nadal criterion).

The criteria discussed above result from:
- the need to meet the normative requirements which are very restrictive in rail transport because they guarantee safe cooperation of the vehicle with the track and infrastructure
- the SIWZ (order details) or OPZ (product description) requirements of a given carrier, which may refer, for example, to the minimum track arc occurring in repair stations, etc.
- the requirements of rolling stock maintenance points, e.g. the availability of components for replacement during repairs, inspections, etc.

Assessment of masses of running gear systems in operation

The list of masses of running gears currently in operation was given in Table 1. As the table below indicates, the weight of standard bogies is normally in the range of 4390 ÷ 4880 kg. The decisive component that influences the weight of the standard running gear in this case is the brake gear, which in the case of one track each way (SS type)

Table 1. List of the weights of standard bogies manufactured and used by Polish carriers

No.	National designation of the bogey	International designation	Total running gear masss [kg]	Wheelset force on the track in kN (t)	Maximum speed when full [km/h]
I	II	III	IV	V	VI
1.	25TNa	Y25Cs2	4450	196kN (20t)	100 km/h
2.	25TNb	Y25Css	4700	196 kN (20t)	120 km/h
3.	25TNd	Y25Csm	4390 ÷ 4510	196kN (20t)	100 km/h
4.	25TNe	Y25Cssm	4655 ÷ 4775	196 kN (20t)	120 km/h
5.	26TN	Y25Rsa	4500 ÷ 4600	196 kN (20t)	100 km/h
6.	26TNa	Y25Rs2a	4500 ÷ 4600	196 kN (20t)	100 km/h
7.	26TNb	Y25Rssa	4630 ÷ 4790	196 kN (20t)	120 km/h
8.	3TN	Y25Lsd	4800	220 kN (22.5t)	100 km/h
9.	3TNa	Y25Ls2d	4800	220 kN (22.5t)	100 km/h
10.	3TNb	Y25Ls(s)	4880	220 kN (22.5t)	100 km/h
11.	3TNf	Y25Lsd1	4800	220 kN (22.5t)	100 km/h
12.	3TNg	Y25Ls(s)1	4860	220 kN (22.5t)	100 km/h

movement (120 km/h) is about 400 kg heavier. It should therefore be concluded that the design of the running gear is most influenced by its purpose related to the maximum pressure of the wheel set on the track, that is the maximum travel speed.

Implications of the adopted assumptions for the design of lightweight running gear systems

Based on the design assumptions adopted, the ultra-light design of running gear must meet many contradictory requirements. One of the most important is compatibility with devices already installed on the railway infrastructure, such as ASDEK, SRK and other devices. Reconstruction of the railway infrastructure in Poland or other EU member states in order to adapt to the design of the running gear is impossible and pointless from the point of view of large financial outlays (the need to abandon the currently used running gear). The problem of compatibility of the vehicle and the related running gear with railway infrastructure devices is a broader issue, which was raised in other papers [2, 6].

Given the above, it can be concluded that ultralight designs of running gear must have external bearings, if it is assumed that this design will be implemented on the transport market. A wheel set with internal bearings is certainly less heavy than a wheel set with external bearings. The validity of this reasoning was confirmed by the design of the running gear called LEILA (LEIchtes und LärmArmes GütewagenDrehGestell). This bogey design was produced in the years 2005–2008 within the framework of Swiss-German cooperation and the Technical University of Berlin. Despite the fact that the weight of the running gear was below 4.000 kg (Fig. 4) and its other undeniable advantages, this system was not implemented into serial production. The running gear has disc brakes, which have a significant advantage of reducing noise emission by 18 dB(A) in relation to standard bogies. As stated by the document ORE/ERRI B12/B36 DT 230 [42], the cost of manufacturing a running gear equipped with brake discs is three times greater than a standard running gear equipped with a lever transmission with brake pads acting on the wheel. It is worth mentioning, however, that the running gear is equipped with a so-called passive radial control mechanism for wheel sets (smaller angles of wheel to rail contact, which guarantees better alignment of the running gear when driving on track curves and lower wear of wheel flanges), (Fig. 1, 2). Unfortunately, it is not possible to check the current technical condition of the running gear suspension during the inspection by auditors before the freight trains are cleared at the station for further travel.

Another issue is related to the brake system design. The use of the K-type brake insert (made of composite materials) seems to be an important element, defining the development trend of the running gear systems of freight wagons. The K-type brake insert, as already mentioned, has a much higher coefficient of wheel-rail friction, depending on the linear speed of the vehicle (Fig. 3). Hence, the forces transferred by the brake system up to the brake cylinder have lower values. Therefore, there is a realistic chance to reduce the mass of the

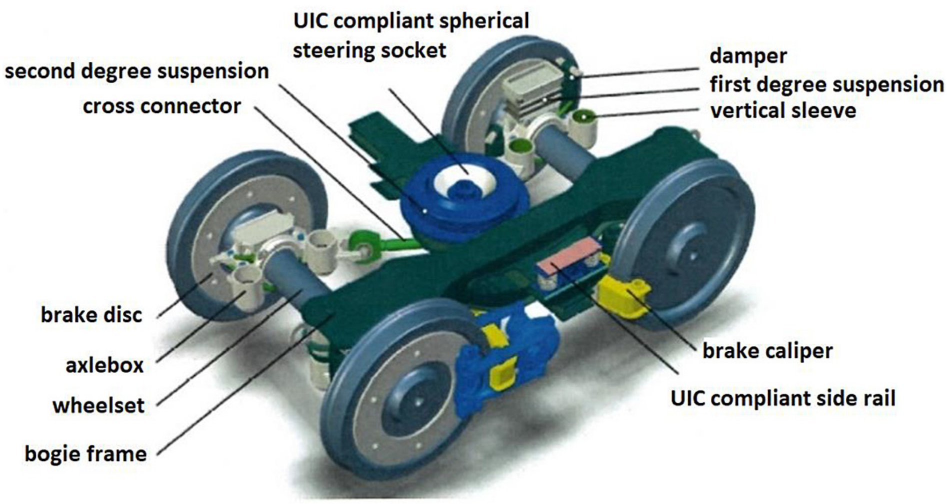

Figure 1. The LEILA -DG running gear system based on [3, 4]

Figure 2. The LEILA-DG running gear system: with radial control of wheel sets in the lower zone, according to [3, 4]

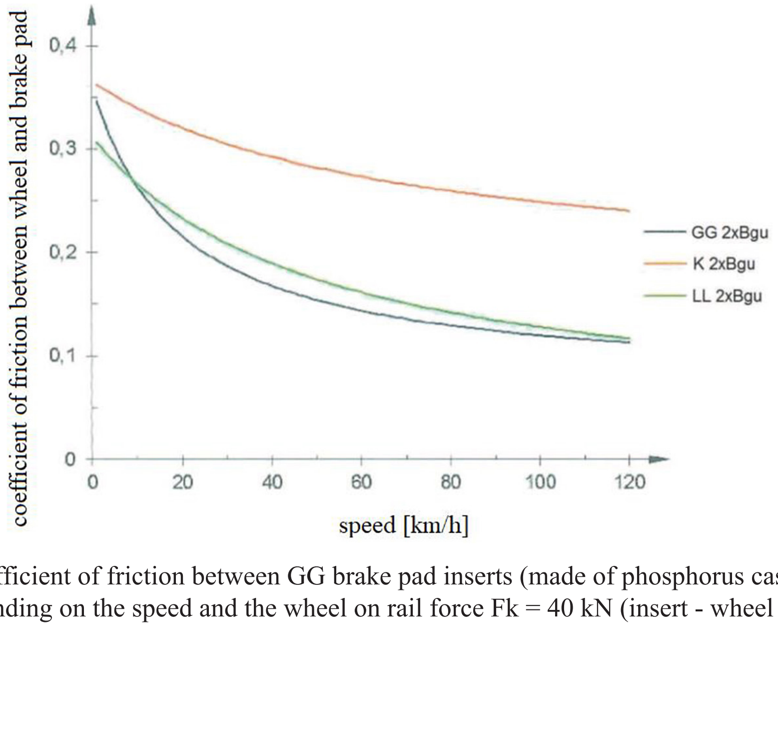

Figure 3. The coefficient of friction between GG brake pad inserts (made of phosphorus cast iron), K and LL type inserts depending on the speed and the wheel on rail force Fk = 40 kN (insert - wheel running surface)

brake system, placed on the running gear and on the body, while maintaining the desired design and operating parameters. The basis for this type of mass optimization could be the standard running gear shown in Figure 4. The advantage of this type of solution is the continuation of the construction nodes from the previous bogies. As a result of using K-type brake inserts, the structure of a brake beam with a smaller mass is created, transferring an operating force of 45 kN. A comparison of the values of forces acting on the brake beam was presented in Table 2. The values of fatigue loads in kN for the brake beams of the bogies (running gears) of freight wagons according to UIC card 833 [36] were presented in Table 3. The deformation values for the brake beams in kN of the bogies (running

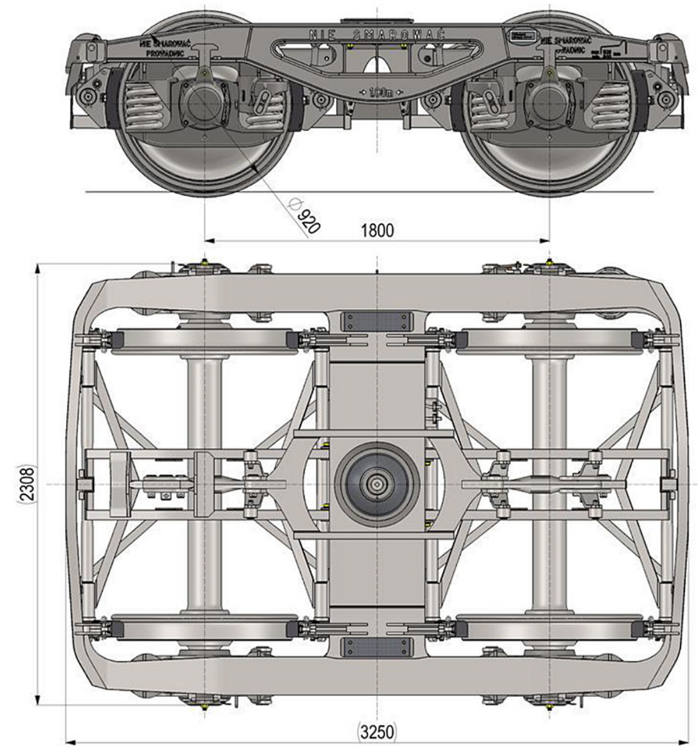

Figure 4. Standard gear system with the so-called light S brake gear (brake beam type 60 kN) and Bgu brake pad

Table 2. Load values in kN for the brake beams of the freight wagons bogies (running gears) according to the UIC card 833 [36]

Brake beam type	Zero load Fok [kN]	Nominal load Fan [kN]	Test load Fep [kN]	Load change limits during fatigue test [kN]
I	II	III	IV	V
Beam 45 kN	5	45	100	5 ÷ 45
Beam 60 kN	5	60	100	10 ÷ 60
Beam 120 kN	10	120	180	20 ÷ 120

Table 3. Fatigue load values in kN for the brake beams of the bogies (running gears) of freight wagons according to the UIC card 833 [36]

Brake beam type	Range of fatigue loads [kN]	Amplitude [kN]	Double amplitude [kN]	Cycle asymmetry coefficient [kN]
I	II	III	IV	V
Beam 45 kN	5-45	30	40	0.111
Beam 60 kN	10-60	25	50	0.166
Beam 120 kN	20-120	50	100	0.166

gears) of freight wagons according to UIC card 833 [36] were presented in Table 4. Due to the need to reduce dead weight, a new design of the 45 kN type brake beam for S/SS traffic was created in accordance with the UIC card 833 [36]. However, with all levers, connectors, rods and brake beams having a lower mass, which was confirmed by the ORE/ERRI B12/Rp.39 report [46]. Another example of optimizing for minimum dead weight was the Y25Lsd-KP1 bogie, shown in Figure 5 and Figure 6. This bogie is equipped with one-sided braking based on a K-type insert, a simplified frame structure consisting of two side beams and a torsion beam, thanks to which it was possible to achieve a dead weight of 4035 kg. The running gear was adapted to a speed of 100 km/h (when loaded) along with the transfer of forces resulting from the wheel set pressure on the track of 22.5 t (220 kN) and to a speed of 120 km/h when empty. Figure 6 shows a simplified design of the braking system. Figure 7 shows the Y25LsAL-C-K running gear manufactured by Tatravagonka-Poprad (Slovakia). The bogie is equipped with one-sided wheel braking system using a K-type insert and a complete cylinder with a lever mechanism to control the insert movement. The frame is made of aluminum alloys. The bogie frame consists of two side members and a torsion beam. Thanks to the lightened structure, a low weight of 3600 kg was achieved.

Another node that should be verified in terms of weight reduction is the primary suspension system and wheel set guidance system called the "axle box system" (Fig. 8). The axle box system of the Y25Cs (Y25L) bogie will be adapted

Table 4. Deformation values for brake beams in kN of bogies (running gears) of freight wagons according to the UIC card 833 [36]

Brake beam type	Elastic deformation Fn [kN]	Plastic deformation Fn [kN]	Elastic deformation Fep [kN]	Test load Fep [kN]	Fatigue test criterion in 106 emergency braking cycles
I	II	III	IV	V	VI
Beam 45 kN	2.0	0.1	3.0	0.5	No damage
Beam 60 kN	2.0	0.1	3.0	0.5	No damage
Beam 120 kN	2.0	0.1	3.0	0.5	No damage

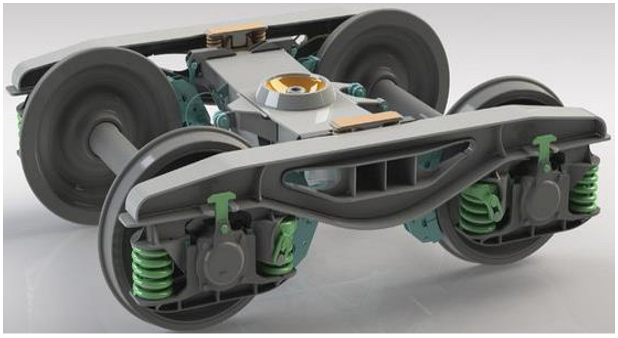

Figure 5. Greenbrier Europe's Y25Lsd-KP1 running gear (side view) [45]

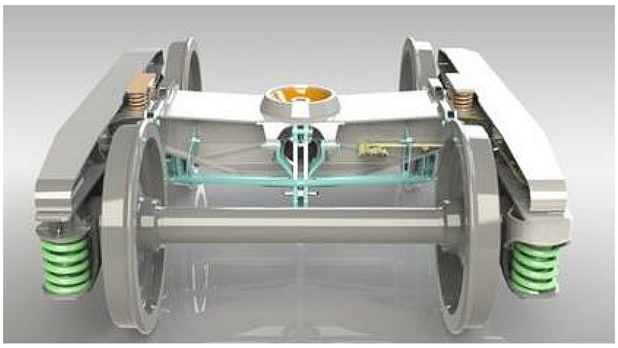

Figure 6. Greenbrier Europe's Y25Lsd-KP1 running gear (front view) [45]

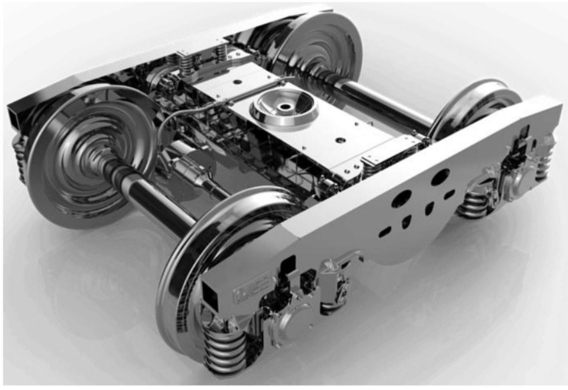

Figure 7. Running gear of the Y25LsAL-C-K bogey manufactured by Tatravagonka-Poprad s.r.o. [46]

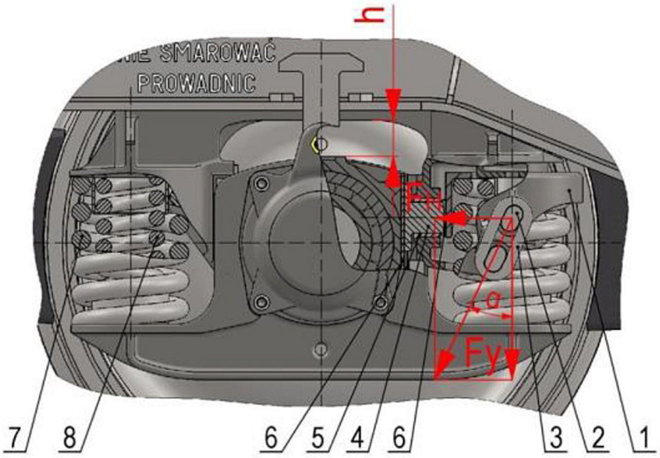

Figure 8. Suspension of the Y25L(Y25C) bogey family where: 1-pressing element, 2-pins, 3-links, 4-friction head, 5-sleeve, 6-friction plate, F, FV, FH- resultant force, vertical force, horizontal force, 7-external spring, 8-internal spring, α-link inclination angle, h-distance from the bumper

to new designs of ultralight bogies. This system has proven itself in the current operation, carried out by many European railway authorities, by adopting a running gear design designed to transfer forces resulting from the wheel set force on the track of 220 kN (22.5 t),. This observation concerns not only the suspension, but also the design of the friction damper. This damper ensures correct dynamic properties in empty and loaded freight wagons, the designs of which were presented in the catalogue [44]. This system does not require relatively many repair and inspection outlays. The mass optimization of this system is possible, but experience so far indicates, that it has resulted in a marginal mass reduction (e.g. replacing the bearings with polyamide cages instead of the existing brass cages). A small clearance between the body of the pressure pad (item 1) and the friction head (item 4) allows for radial positioning of the wheel set in track arcs [5, 6]. Figure 9 shows the dependence of the vertical deflection of a freight wagon suspension in relation to the load exerting it. The graph was created based on data included in the design documentation of standard bogies and in the UIC 517 card [33] and the study [6]. The characteristic is progressive, i.e. lower stiffness (higher flexibility) is in the empty state, in which case only the external springs of the suspension work. The progression point, the moment when the internal springs theoretically begin to engage, corresponds to the wagon mass of 26.559 kg. In the case of a mass greater than 26.559 kg, the stiffness of the suspension increases. Such a characteristic, called a progressive characteristic, is beneficial from the safety against derailment perspective and has proven itself during operation [6, 7]. A freight wagon has suspension with greater flexibility when driving empty (when load being reduced on a wheel when driving on twisted tracks is much more dangerous) and suspension

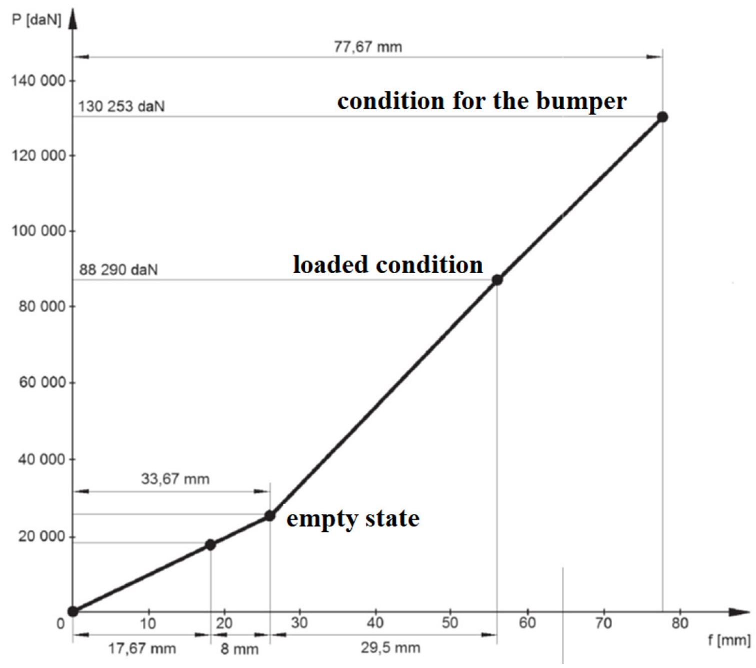

Figure 9. Characteristics of the suspension of a freight wagon according to [6] where: 1. ordinate axis - the gravity force of the wagon, 2. abscissa axis - deflection of the bogie suspension

with less flexibility when the risk of derailment while driving on warped tracks with the maximum permissible warp is much greater.

The stiffness of the springs, the spring set, the axle suspension and the entire running gear, adapted to transfer the forces resulting from the wheel set pressure on the track of 220 kN (22.5 t) were presented in Table 5.

LIMITING FACTORS OF WEIGHT REDUCTION

The factors limiting the reduction of the tare weight include:

- the need to transfer vertical, lateral, twisting, rhomboidal and braking forces through the bogie frame with all the beams, as outlined in PN-EN 13749:2021 [21]
- the need to maintain the deflections of the components at the same, permissible level. It should be noted that the permissible deflection vector must remain at the same level. This particularly applies to the wheelset and is related to the criterion of the permissible distance between the wheel flanges in the rail head zone, which in a static state is 1360 + 2 mm, while during travel 1360 ± 3 mm. In such cases, stresses are not the only criteria for assessing the axle design. The same applies to the design of the brake beam, where the deflection vectors must remain at the same level due to the limited stroke of the brake pad adjuster. In the case of the bogie frame, the vertical deflection is limited by the required range of the buffer heights and the screw (or automatic) coupling measured from the rail head level,
- the need to ensure collision-free operation of the subassemblies and their elements during

Table 5. Comparison of the stiffness and flexibility of the suspension of the trolley adapted to a pressure of 220 kN (22.5 t)

No.	External spring stiffness	Internal spring stiffness	Spring set stiffness	Axle box suspension stiffness	Bogey suspension stiffness	Bogey suspension flexibility
I	II	III	IV	V	VI	VII
1.	kN/mm					mm/kN
2.	empty cargo wagon					
3.	49.80	-	49.8	99.6	398.4	2.51×10^{-3}
4.	Full cargo wagon					
5.	49.80	82.17	131.97	263.94	1055.76	9.47×10^{-4}

all possible operating conditions resulting from driving on a track with a different trajectory, suspension deflections and wheel wear conditions,
- ensuring compatibility with current railway infrastructure devices, especially with any ASDEK system devices,
- maintaining the bogie structure outline within the reference outline of the kinematic gauge in accordance with the European standard PN-EN 15273-2+A1:2017 [23], taking into account any extreme displacements resulting from the play of the wheelset in the track, lateral play between the axlebox body and the guide roller body, maximum suspension deflection and wear of the wheels of the wheelset,
- the need to use monoblock wheels resistant to thermomechanical loads and; the use of "K" type inserts (made of composite materials) causes significant emission of heat generated during braking to the wheel rim (composite materials have a relatively low heat transfer coefficient); one of the technological methods is to increase the range of negative residual stresses in the wheel rim; compressive stresses in the wheel rim have the opposite sign to tensile thermal stresses; these stresses prevent cracks in the wheel rim surface; another inhibiting factor is the grain refinement of the chemical structure and the degree of smoothness (roughness) of the wheel rim surface; the above-mentioned wheel features contribute to the formation of a compact surface layer, resistant to the formation of cracks and the beginnings of fatigue cracks; ensuring the achievement of maximum durability of monoblock wheels; the above can be achieved by appropriate use of economical turning, using the so-called intermediate profiles according to the European standard PN-EN 13715:2020 [19].

It can be noted from the presented running gear designs, that reducing the tare weight is possible. An important factor in this development trend is environmental protection, which is becoming a priority goal. The second important development factor, which is of great importance, is achieving the maximum payload of wagons. This factor is the result of increasing competition in the freight transport sector. The lower the tare weight of wagons, the greater their potential payload. The dominant trend concerns running gears for four-axle freight wagons, adapted to transfer forces resulting from the wheelset pressure on the track of 220 kN (22.5 t) and a speed of 100 km/h when loaded and 120 km/h when empty (wagons with a gross weight of 90 t). Freight trains consisting of four-axle wagons weighing 100 t (running gears adapted to transfer forces resulting from the wheelset force on the track of 245 kN (25t) as shown in driving tests, run on selected railway routes. The popularization of such transport would require infrastructure investment for the construction or modernization of railway routes, and this is associated with financial outlays. Increasing the gross weight of four-axle freight wagons is associated with running gears with a greater tare weight (estimated at 11% greater). An important factor that remains unchanged as one of the basic ones is the safety of running a freight wagon, which is very much influenced by the design of the running gear. The criteria presented below are related to this.

$$\frac{Y}{Q} = \frac{tg\gamma - \mu}{1+\mu\tan\gamma} \leq 1.2 \tag{1}$$

where: Y- transverse force acting on a 2 m long track span, Q- actual vertical force of a wheel on the rail, μ- wheel-rail friction coefficient, γ- wheel flange inclination angle.

The above criterion (also known as the Nadal criterion) applies for a wheel-rail friction coefficient of μ = 0.36, at a low driving speed v = 3 ÷ 5 km/h (so-called quasi-static conditions) and a rim angle of γ = 70° (wheel in new or unworn condition). The second criterion applies when driving at any speed:

$$\frac{Y}{Q} = \frac{tg\gamma - \mu}{1+\mu\tan\gamma} \leq 0.8 \tag{2}$$

In the above case, the wheel-rail friction coefficient decreases with speed, while the flange angle may decrease to γ = 60° due to wear.

Third criterion related to passing through switches and track crossings:

$$\frac{Y}{Q} \leq 0.4 \tag{3}$$

In this case, the steering wheel angle is decisive. By analyzing all three criteria, it can be concluded that derailment safety may be a significant factor limiting the reduction of the freight wagon tare weight (which includes the running gear).

In this case, the decisive factors limiting the reduction of the overall tare weight are the tare weight of the freight wagon in an empty state, which is associated with the reduction of the weight of the running gear, while maintaining the same suspension system (Fig. 3). It should be taken into account that in the case of an empty wagon, the factor determining the driving safety is the relief of the wheel ΔQ or the reduction of the nominal force Q0, caused, for example, by passing over a cant ramp of a track with a gradient of 2‰, vertical track unevenness, asymmetry of the wagon structure, dispersion of the spring flexibility, etc. In this case, when the nominal force Q0 is smaller (lightened structure), then the relief ΔQ due to maintaining the same spring stiffness (the loaded condition is decisive for its maintenance) is at the same level (it arises as a result of kinematic excitation). The criterion of the minimum tare weight of a freight wagon, given in UIC sheet 432 [28], confirmed by simulation tests, is 16 t. Analyzing the safety of wagons with new running gears, it should be noted, however, that the bogie frames after eliminating some of the front beams and longitudinal beams show lower torsional stiffness (greater susceptibility to deformation when passing through twisted tracks). Therefore, lower torsional stiffness can be expected than previously measured on the test stands, i.e. 1.5×10^{10} kN/mm×rad^2. If so, the torsional stiffness of the Y25LsAL-C-K bogie is lower than that of the standard Y25 family bogie with a traditional braking system and frame.

EMISSION OF CONSUMPTION PRODUCTS INTO THE NATURAL ENVIRONMENT

The running gear components of freight wagon bogies include the following wear products that are emitted into the natural environment:

- wear of the pivot socket insert and the linings of the elastic side slides (composite materials),
- wear of pins and bushes in the brake system (surface-hardened steel C55 E),
- wear of the monoblock wheel rims made of ER7 steel as required by PN-EN 13262+A1:2021[19],
- wear of type K inserts (made of composite materials),
- wear of category E plates according to UIC card 893 [34] (as sliding plates welded to the axle box bodies and guide bodies) and in the area of the friction damper [35].

To date, no serious analysis has been done on the quantitative and qualitative impact of wear products on the natural environment. The environmental impact of released consumption products increases with the level of use of a given railway line, especially with an increase in rail freight transport, which translates into the kilometer mileage of a given freight wagon on an annual basis.

NOISE EMISSION

The problem of rail transport noise emission was discussed in previous studies [4,6]. Very important views on noise emission were provided by the PN-ISO 1996-1:2006 standard [27]. This standard refers to scientific research, which has shown that the negative impact of sound sources related to transport is different for different means of transport. The results of the empirical studies conducted include conclusions such as:

- for the same sound level equivalent values, aircraft noise is less bothersome than road noise, especially in the moderate to high noise level range,
- rail noise is less bothersome than road noise, especially in the moderate to high noise level range.

However, the conclusion regarding railway noise can only apply to short (usually 12 to 20 wagons) electric traction trains. There was no data which would extend this conclusion to be applicable to long [11] (usually 50 to 100 wagons) diesel trains or trains moving at speeds exceeding 250 km/h. It follows that extending the length of trains from 750 meters to 1000 meters or even 1500 meters can already lead to greater noise impact. A summary of typical corrections to the sound level, determined based on the sound source category and time of day was presented in Table 6.

As stated in PN-B-02151-02:1987/Ap1:2015-05 [29], an important criterion for assessing noise emission is the A-weighted sound level in rooms where people stay.

The permissible equivalent A-weighted sound level of noise penetrating a room from all noise sources together LA,eq [dB] is divided into nighttime and daytime. Then, depending on the purpose of the room, it should be in the range of 30–45 dB(A) for daytime and 30–40 dB(A) at night. At night, a lower noise emission level usually applies. Noise emissions can be closely linked to human health and wellbeing. Therefore, the broadly understood issue of combating noise in the case of rail transport takes on priority

Table 6. Sound level corrections determined based on the sound source category and time of day according to PN-ISO 1996-1:2006 [27]

Type	Category	Noise level correction
Noise source	Road traffic	0
	Air traffic	3 ÷ 6
	Rail traffic[1)]	-3 ÷ -6
	Industry	0
Source type	Typical impulse noise[2)]	5
	high impulse noise	12
	High-energy impulse noise	see: att. B of the norm
	Distinctive tones[3)]	3–6
Time	Evening	5
	Night	10
	Weekend, dayime[4)]	5

Note: [1)]The railway noise corrections do not apply to long trainsets with a diesel locomotive or trains running at speeds above 250 km/h; [2)]In some countries, objective "distinctiveness" tests are used to determine whether sources are typical impulsive sources; [3)]If the presence of a distinctive tone component is in dispute, it is recommended to use the auxiliary procedures according to PN-ISO 1992-2/A1:2002 [28] to test its presence; [4)]For Ld, a correction for daytime during the weekend, specified by the appropriate authorities, is added.

importance and design assessment process for each rail vehicle, including a freight wagon and its associated running gear.

CONCLUSIONS

1. The pursuit for tare weight reduction of running gear systems of freight wagons must not interfere with the ability to maintain all the current criteria of design and construction assessment, provided that noise emission is gradually reduced.
2. Reducing the tare weight of the running gear system has its logical beginning in braking system changes, which lead to its simplification and reduction of its noise emission. Along with the simplification of the braking system, it turns out that the construction of the bogie frame can often be significantly simplified. As shown, it is possible to do away with the bogie end frames (an element made of a channel and bent in two planes) and two longitudinal beams. Brackets for suspending the braking system in traditional bogies, made according to standard documentation, were welded onto these elements. The search for smaller masses of wheel sets, which include wheels and axles, seems reasonable based on the current state of knowledge for several reasons: in addition to permissible stresses, another criterion is permissible deflections of the axle and wheels, which, should not exceed permissible values, the design of the wheelset guarantees preserving the dimensions of the guide width, the lateral distances of the wheel rims, etc.
3. When using new ultra-light running gears in the process of homologating freight wagons, full tests should be performed according to the European standard 14363+A1:2019 E, P [21] to check their driving safety and dynamic properties. The frame should be subjected to static and fatigue tests using strain gauges on a certified test stand for compliance with the European standard PN-EN 13749:2021 [20]. Newly designed 45 kN brake beams must be subjected to static tests (8 pieces) to check the deflection and permanent deformations, as well as fatigue tests (2 pieces).
4. Authorizing an ultra-light bogie to be used in international rail traffic does not mean that it meets the criteria for driving safety and dynamic properties in every type of freight wagon, as they differ from each other in terms of base and tare weight. In freight wagons with a relatively low net weight, close to 16 t, it is mandatory to check the driving safety and dynamic properties in field tests.
5. The environmental impact should be taken into account already in the process when designing ultralight rail bogies. The most important ecological issues that should be considered include: reducing the emission of wear products and the emitted reducing vibrations and noise.

As it turns out, environmental protection criteria are currently the most important factor determining the acceptance and approval of the running gear for commercial use.

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