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Bogie design of 227M type rail vehicle

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The article presents the running parameters and construction of the 41MN and 46MN hybrid traction units (HZT). Design solutions were presented and described, attention was paid to the functions fulfilled by individual systems of rolling and driving bogies.The article was created as part of an ongoing project as part of Program Badań Stosowanych 3 Umowa Nr PBS3/B6/26/2015 „Lekki autobus szynowy do ruchu regionalnego".

1. Introduction

One of the design goals assigned to the 227M vehicle is to meet the TSI (Technical Specifications for Interoperability) specifications for the vehicle. The designed 41MN and 46AN running gear systems, in order to comply with the TSI, have to meet specific requirements, which include:

1. environmental requirements
   - working temperature zone, humidity acc. to EN 50125-1
   - pollution resistance
2. interaction of the vehicle on the track
   - track gauge (EN-15273-2)
   - axle load (determined by the category of the railway line)
   - running gear parameters affecting trackside equipment (EN-15437-2)
   - dynamic behavior of the vehicle on the track [6]
     - safety against derailment EN 14363[10]
     - running dynamics EN 14363
     - vehicle running safety EN 14363
     - track load EN 14363
     - equivalent conicity
     - wheel profile parameters [8, 9]
     - the service life of the wheelset [7]
3. running gears systems
   - bogie frame (EN-13749)
   - parameters of wheelsets EN 13103, EN 13104
   - wheel profile geometry EN 13979:1
   - minimum curve radius of the track
   - positioning the rail scrapers above the rail head
4. brakes
   - braking performance – emergency and service braking, heat loads, parking brake EN 15431-1, EN 15431-6
   - adhesion index – adhesion coefficient depending on the type of vehicle, anti-skid systems – EN 15595
   - brakes independent of adhesion force UIC 541-06
   - requirements for brakes in the event of an emergency.

Two types of bogies have been designed for the needs of the 227M (FPS PLUS) vehicle:

- 41MN – motor bogie, with subtypes 41MNa and 41MNb differing in the arrangement of sensors on the bearing housings and, consequently, in the arrangement of electric wires (Fig. 1)
- 46AN – rolling bogie, with the subtypes 46ANa and 46ANb, differing in the arrangement of sensors on the bearing housings and, consequently, in the arrangement of electric wires. They are located on the edge of the vehicle (Fig. 2).

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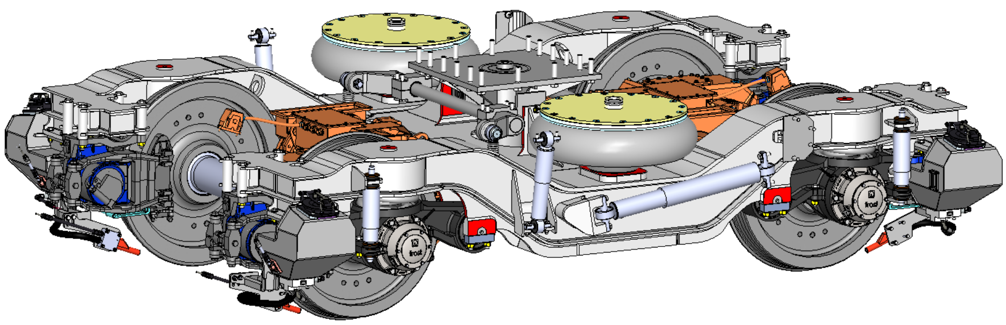

Fig. 1. Driving bogie type 41MN

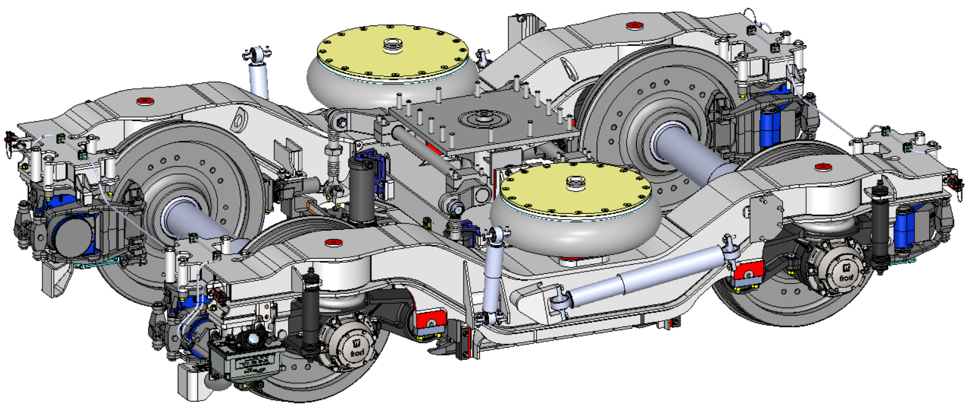

Fig. 2. Rolling bogie type 46AN

Table 1. Basic parameters of 44MN/46AN bogies

Parameter	46AN rolling bogie	41MN motor bogie
Design speed of the vehicle	176 km/h	
Track gauge	1435 mm	
Wheelbase of wheelsets (bogie base)	2500 mm	
Wheel diameter (new/ worn)	ϕ850/ϕ780 mm	
Vehicle weight (empty)	~100 000 kg	
Bogie weight	7.05 t ±3%	9.2 t ±3%
Engine power	–	2 × 300 kW
Gear ratio	–	5.98
Maximum load of a wheelset on the track	18 t	
Wheel rim width	135 ±1 mm	
Maximum permissible wear of the brake block	30 mm	
Maximum permitted wear of the brake disc	7 mm	
Permissible radial wheel wear	35 mm	
Center distance of wheelset axial bearings	2100 mm	
Axial bearing	TBU130 × 230 × 160	
Primary suspension bumper clearance (vertical)	40 mm (+Z) 30 mm (–Z)	
Secondary suspension bumper clearance (vertical)	64 mm	
Lateral movement of the bogie in relation to the body of the vehicle	50 mm	
Minimum permitted radius of track curve	150 m	
The maximum steering angle of the bogie in new condition	4º40'	
Largest lateral movement of a wheelset relative to the bogie frame (per side)	3 mm	
Axle journal dimensions:	ϕ130 × 217mm	
Brake:	disc brake mounted on a wheel (pneumatic-mechanical); rail brake; parking brake	disc brake mounted on a wheel (pneumatic-mechanical); parking brake
Additional equipment	lubrication of the wheel flanges together with the reservoir cleaning brake block	heated sandblasting nozzles and sand tanks cleaning brake block
Bogie gauge	according to the UIC-505-1 (p. 5.2) card	

The bogies are characterized by good running properties in terms of safety and driving comfort, minimized wear of the running surface of the wheels, maintenance-free nature of the operation of individual components and simple design. The basic parameters of the bogies are presented in Table 1.

2. Bogie design

2.1. Bogie frame

The frame of the bogies is a spatial, open-type welded structure that has been unified as much as possible so that the differences between the rolling bogie and the motor bogie are insignificant. The frame consists of two longitudinal side beams connected by a crossbar and four small end beams. All its elements are made of S355J2 + N low-alloy structural steel with increased strength, which chemical composition is presented in Table 2.

Table 1. Chemical composition of S355J2 + N steel

C	0,2
Mn	1.5
Si	0.2–0.5
P	≤ 0.04
S	≤ 0.04
Cr	≤ 0.3
Ni	≤ 0.3
Mo	–
W	–
V	–
Al	≤ 0.02
Cu	≤0.03

All beams form a closed box structure. In the central part of each side beam, an air spring support is welded on its upper flange. On each of the side beams there are vertical shock absorbers and link-arm mounts. End beams located at the ends of each side beams act as a brackets for the installation of sand-blast nozzles or supports for the scraper and the wheel flange lubrication system. The brackets for the brake caliper mechanisms are located on the end beams as well. On the crossbar there are supports for the drive system, bumpers, horizontal shock absorber and the tractive force transmission system. The differences between the types relate to the presence of the drive system and the rail brake. Figure 3 shows:

- gray – common frame structure elements for both types
- red – frame structure elements present only on the motor bogie (propulsion suspension brackets)
- green – frame structure elements present only on the rolling bogie (rail brake suspension brackets and its longitudinal buffers).

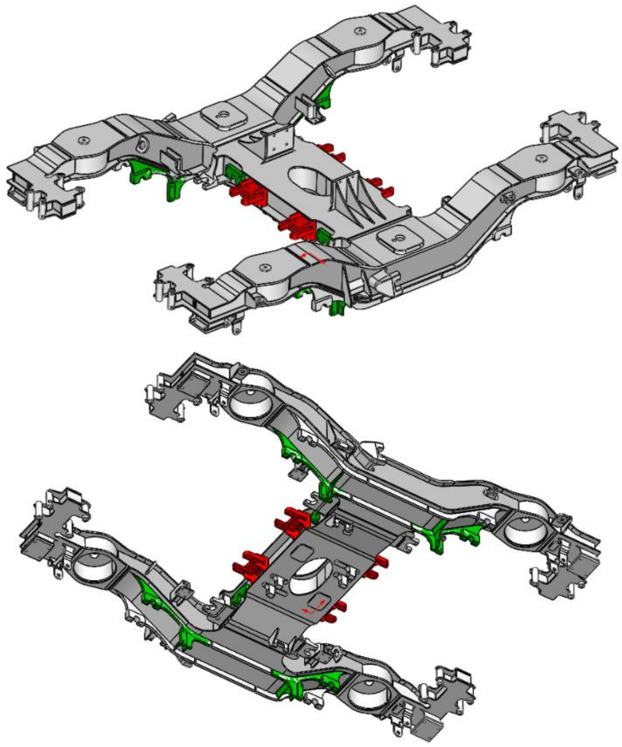

Fig. 3. Complete bogie frame with brackets

2.2. Wheelset

Each bogie is equipped with two forged and rolled wheelsets with rimless wheels with a rolling circle diameter of ϕ850 mm in new condition and the wheel outline S1002/h28/e32.5/6.7% in accordance with PN-EN 13715:2008. The permissible diameter of the wheel when worn is ø780 mm. The rimless wheel is adapted to the installation of brake discs. The wheelsets of the motor bogies have been adapted to the installation of axle gears (Fig. 4).

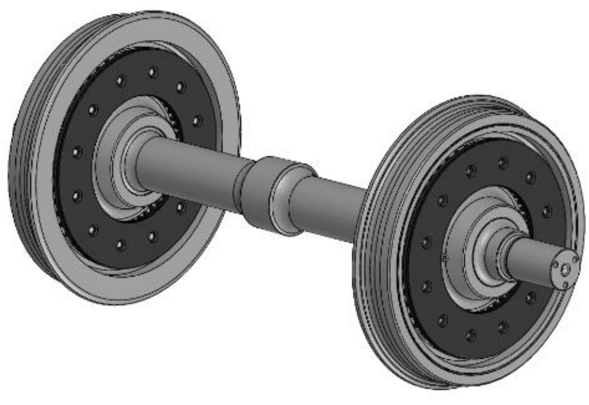

Fig. 4. Isometric view of the wheelset of the motor bogie

2.3. Wheelset steering and primary suspension

The wheelset is guided in the bogie frame by means of two casted link-arms consisting of three parts (three-piece design), i.e. the upper part, lower clamp and bearing housing. Castings are common to both types of bogies (rolling and motor). The link-arm is connected to the bogie frame through a rubber-metal joint (Fig. 5) manufactured by Contitech, the stiffness of which is shown in Table 3.

Table 2. The stiffness of the rubber-metal joint

Stiffness	Stiffness value
radial in the X axis	21.2 kN/mm ±14%
axial in the Y axis	25.2 kN/mm ±14%
radial in the Z axis	3.7 kN/mm ±20%
cardanic about the X axis	660 Nm/grad ±13%
torsion about the Y axis	250 Nm/grad ±15%
cardanic about the Z axis	2770 Nm/grad ±15%

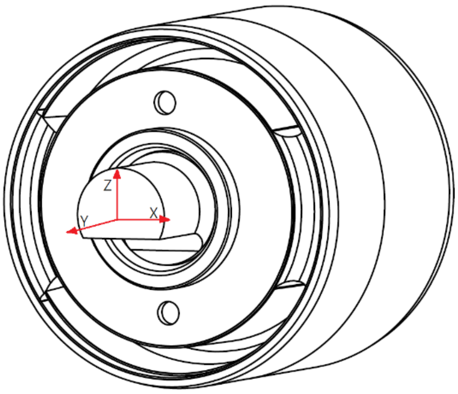

Fig. 5. Isometric view of a rubber-metal joint

The transfer of vertical forces is performed by a set of three coil springs (Fig. 6). The use of as many as three springs results from the necessity to ensure safety against derailment for a wide range of vehicle loads and a small amount of space available for the installation of the springs. The springs are made of 52CrMoV4 + HH spring steel in accordance with the PN-EN 10089 standard.

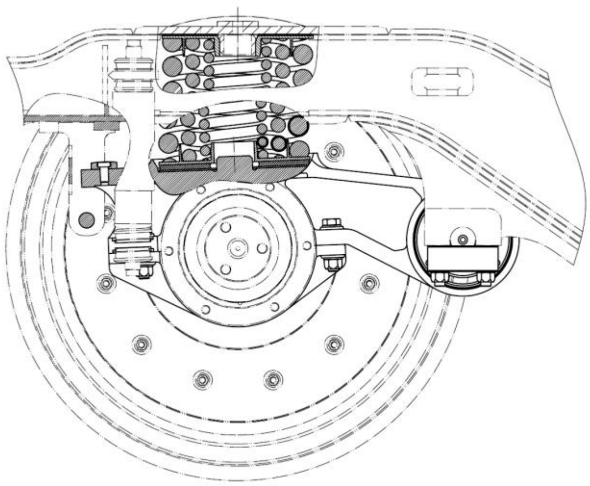

Fig. 6. Primary suspension of 41MN and 46AN bogies

The required distance between the bogie frame and the rail head is achieved by the use of adjustment washers, which are placed on the upper guiding spacer. The springs stand on the lower metal-rubber spacer, which not only serves as a spring guiding element, but also compensates for the non-parallelism of the bases resulting from the work of the link-arm (reduces the buckling tendency of springs) and act as a counter-current insulation. The properties of the primary suspension and the wheelset steering of 41MN/46AN bogies are presented in Table 4.

Table 3. Properties of the primary suspension and the wheelset driving on bogies type 41MN and 46AN

Parameter	Unit	Value	
		41MN	46AN
Diameter of outer/middle/ inner spring bar	mm	38/28/19.5	38.5/29/20
Pitch diameter of outer/ middle/inner spring	mm	255/176/ 112.5	255.5/175/ 113
Total number of turns of outer/middle/inner spring	–	4.9/6.5/9.3	5/6.5/9.2
Number of active turns for outer/middle/inner spring	–	3.4/5/7.8	3.5/5/7.7
Length of outer/middle/inner spring unloaded	mm	309/309/30 9	318/310/ 314
The length of the springs under receiving load P_0	mm	236	236
Height of the springs loaded to the maximum	mm	196	200
Deflection of outer/middle/ inner spring loaded at maximum	mm	113/113/ 113	118/110/ 114
Compliance of the outer/ middle/inner spring	mm/kN	2.76/4.52/ 7.78	2.67/3.82/ 7.08
Primary suspension springing stiffness for empty/ loaded conditions	kN/mm	1.12/1.16	1.21/1.25
Damping force of a vertical damper at V = 0.1 m/s (tension/compression)	kN	0.55/0.45	
Damping force of the vertical damper at V = 0.3 m/s	kN	1.1	
Maximum cross movement of the wheelset relative to the bogie (per side)	mm	3	

Vibration is damped by a vertical hydraulic shock absorber. Limiting the vertical movement of the wheelset is realized in the form of a metal bumper installed between the link-arm and the frame, and a pin preventing the wheelset from falling onto the track while lifting the bogie. These limiters also protect the drive system against damage resulting from excessive displacements.

2.4. Secondary suspension

The secondary suspension (Fig. 7) consists of two sets of air springs with rubber-metal springs of the emergency body support. The springs carry out lateral movement and rotation of the bogie in relation to the car body. The power supply and pneumatic spring control system is built on the body of the vehicle. The constant height of the springs, irrespective of the load, is maintained by weighing valves installed on the vehicle's frame and articulated with the bogie frame. Adjusting the height of the vehicle body from the rail head is possible through the use of adjustment washers under the rubber-metal springs of the emergency backrest. The maximum load of one set of springs is 170 kN with a supply pressure of 5.8 bar.

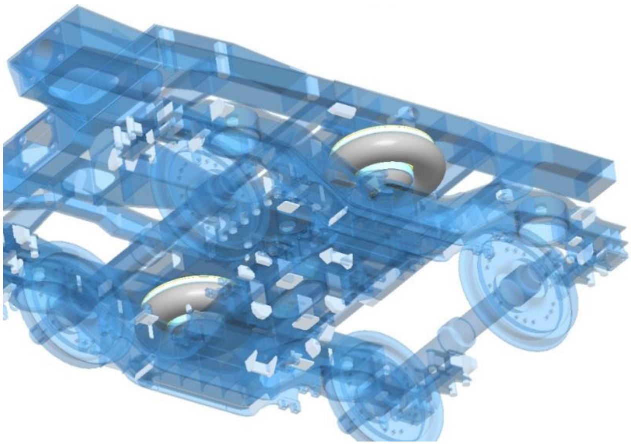

Fig. 7. Secondary suspension assembly for 41MN and 46AN bogies

2.5. Drive system

The bogie drive system (Fig. 8) consists of two sets: traction motor – diaphragm clutch on the motor side – gear mounted on the bogie frame: on one side it is mounted by a gear wheel and a bearing and suspension system by means of a flexible segment coupling on the wheel set axle, on the other sides attached by rubber-metal elements to brackets welded to the frame of the bogie.

The traction motor is a 3-phase asynchronous motor with a squirrel cage rotor designed for operation with a frequency converter. The motor is equipped with rotational speed sensors and with Pt100 thermometric sensors for temperature measurement of the stator windings (temperature setting values: warning 170°C, disconnection 180°C). The traction motor has external cooling. Cooling air is supplied from the vehicle by a corrugated bellows and discharged from the engine through ventilation grids. The basic parameters of the traction motor are shown in Table 5.

The traction motor is flange-mounted directly to the gearbox, thus no motor bearing is needed on the gearbox side. The rotor shaft is connected to the transmission input shaft by a flexible diaphragm coupling. There is a sliding roller bearing on the gear side. The traction motor with the transmission is suspended on the trolley of the vehicle by means of rubber-metal connectors.

The basic parameters of the traction gear are shown in Table 6.

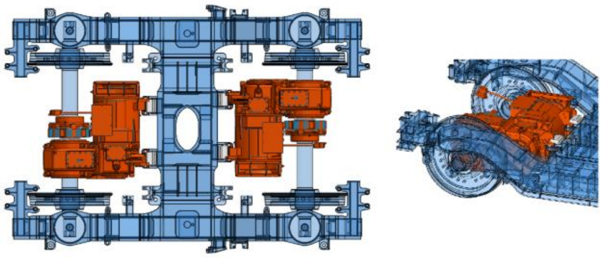

Fig. 8. Drive system of the 41MN bogie

Table 5. Basic parameters of the traction motor

Parameter	Unit	Value
Operating mode	–	S1
Power	kW	300
Voltage	V	2340
Current	A	96
Rotation speed	min^{-1}	2139
Frequency	Hz	72
Efficiency	%	94.3
Power factor cos φ	–	0.82
Torque	Nm	1339
Moment of inertia of the rotor mass	kgm^2	2.1
Weight	kg	engine without accessories – 629 diaphragm clutch – 31 rotor – 191
Insulation	–	VPI impregnation, thermal class 200 according to IEC 349

Table 6. Basic parameters of the traction gear

Parameter	Unit	Value
Type of transmission	–	two-stage
Gear ratio	–	5.98
Maximum rotation speed	min^{-1}	6570
Maximum transmittable torque	Nm	2846
Weight	kg	580 (gear with clutch) 85 (clutch only)

2.6. Traction force transmission

The longitudinal and transverse forces between the body and the bogie are transferred by means of a torsion pin bolted to the vehicle frame and then through the lower part of the towing device assembly to the bogie frame (Fig. 9). The towing apparatus unit is built on the steering pin on tapered roller bearings. Forces are transferred to the frame by means of two parallel guides with ball joints. In the longitudinal direction, the connection is backlash-free. In the transverse direction, after exhausting the allowed free play, the assembly cooperates with the rubber-metal bumpers. If it is necessary to lift the car body with the bogie after exhausting the vertical play between the bogie frame and the towing unit, the bogie is lifted through the pivot pin with the towing device assembly.

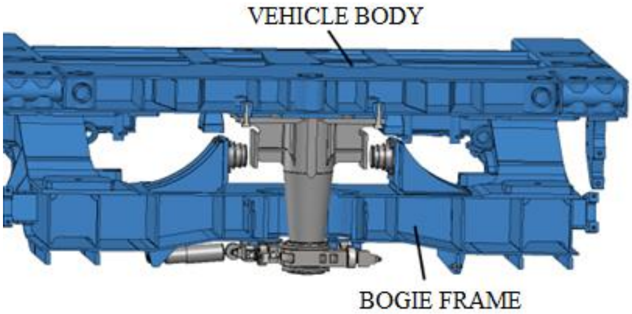

Fig. 9. System of transmission of tractive force in bogies type 41MN and 46AN

2.7. Brake actuators on bogies

The 227M vehicle for which the motor and rolling bogies have been designed is equipped with the following types of brakes mounted on the bogies:

- electrodynamic brake (ED) using the braking force from shifting the traction motor to generator operation - acting on the driving bogie
- direct type electro-pneumatic brake (EP-B)
- pneumatic combined brake (PN)
- a system of blocks that clean the rolling surfaces of the wheels, improving traction (KC)
- electromagnetic friction rail brake (Mg) –mounted on a rolling bogie
- parking spring brake (PS) – mounted on a trolley.

Two ϕ680/390 × 135 mm brake discs are mounted on each axle of the vehicle. The brake disc consists of two friction rings, called internal or external, depending on their position in relation to the wheel rim. The friction ring thickness and the number and geometry of the cooling fins are designed to keep the friction ring temperature within the acceptable range and minimize thermal and mechanical loads. In addition to heat dissipation, the cooling fins also support the friction ring on the wheel. Brake discs mounted on the wheels of the vehicle provide greater braking power compared to the classic solution consisting in the installation of the disc on the axle. It is directly related to the larger dimensions of the disc, which enable obtaining large friction radii.

Each axle of the vehicle is equipped with two brake calipers. Two types are used, the first has only an air brake cylinder, the second has an air brake cylinder and a spring brake cylinder. The compressed air pressure creates the braking force in the air brake cylinder. A "low" force spring serves to loosen the clamp when the pressure is released. In the spring brake cylinder, the braking force is generated by a "large" spring force. Applying compressed air creates a counter force. When the pressure is exceeded, the spring brake caliper is completely released. Each brake caliper is equipped with a stroke adjuster to minimize wear on the brake linings. The vehicle uses JURID 878 organic brake linings in accordance with UIC requirements – 200 cm^2 (400 cm^2 two halves) with a nominal thickness of 35 mm. In the vicinity of each wheel, pneumatic blocks are installed to clean the wheel tread from possible stickers, ensuring the optimal wheel-rail friction coefficient.

All elements of the braking system are controlled and powered from appropriate pneumatic panels. The actuators of the brake installed on the 41MN/46AN bogies are shown in red in Fig. 10.

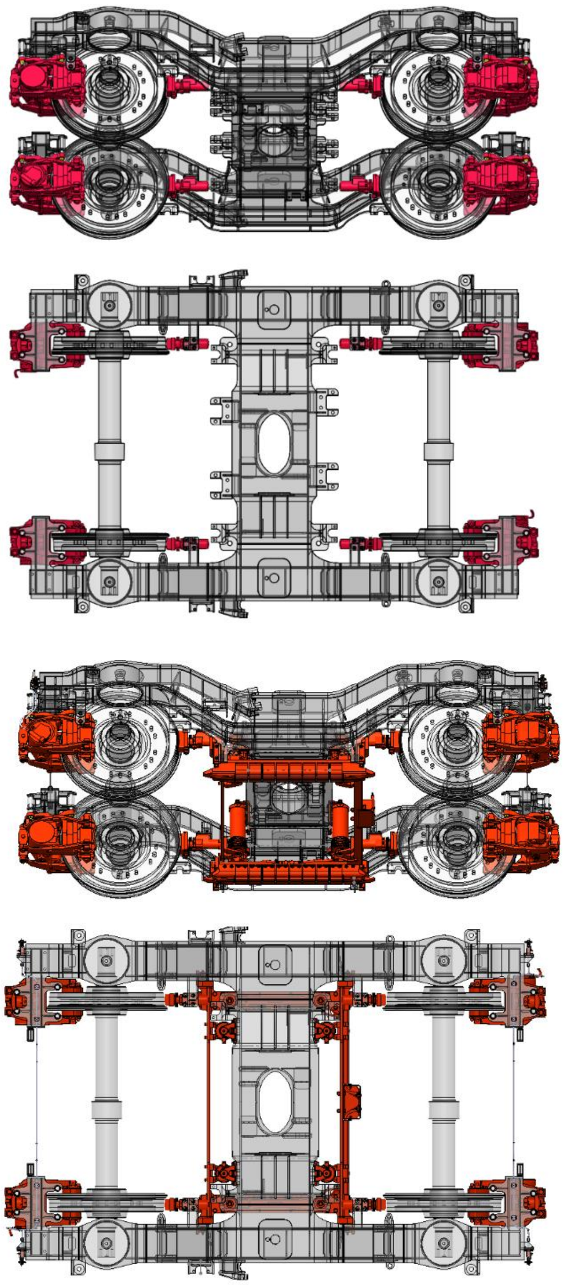

Fig. 10. Braking system of the 41MN type bogie (above) and the 46AN type bogie (below)

2.8. Anti-roll bar

The anti-roll bar is an element connecting the bogie frame with the vehicle body. It consists of a tube connected to the arms and adjustable levers attached to the vehicle's underframe. The torsional stiffness of the stabilizer is 1.5 MNm/rad. The levers have articulated ends enabling the stabilizer to rotate in relation to the trolley. The shape of the stabilizer arms allows for its collision-free operation when the body is fully turned in relation to the bogie.

Each of the bogies is equipped with two anti-roll bars. The use of this in the vehicle reduces the roll coefficient of the body and ensures the correct fit of the pantograph to the vehicle gauge by increasing the angular stiffness of the suspension. Its use allows to maintain the aforementioned coefficient of body roll in the range of $S \leq 0.4$. The simulation tests carried out showed that the coefficient value was 0.36 in the loaded state and 0.25 in the empty state. The installation of the tilt stabilizers is shown in Fig. 11.

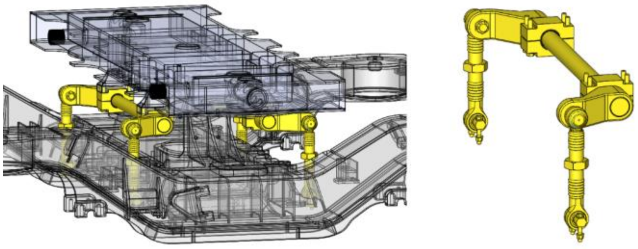

Fig. 11. Body anti-roll bar

2.9. Axle bearing housing arrangement

Axle bearing housings perform several functions:

- they are a housing for axial bearings, in the presented bogies, maintenance-free sealed bearings of TBU type are used,
- they are the mounting of the wheelset through the rocker arms to the frame of the bogie,
- devices and sensors responsible for the safety and driving of the vehicle are fixed to the front of the bearing housing body.

All axial bearing housings (Fig. 12) are equipped with temperature sensors. Each axle of the wheelset in the driving and rolling bogies has one axle bearing housing equipped with a grounding device (stiffening brush), in addition, one axle box on the axle has a built-in sensor for the anti-skid brake system, the other axle bearing housings are equipped, depending on the needs: with sensors for ETCS system and speedometer transmitter for the recorder.

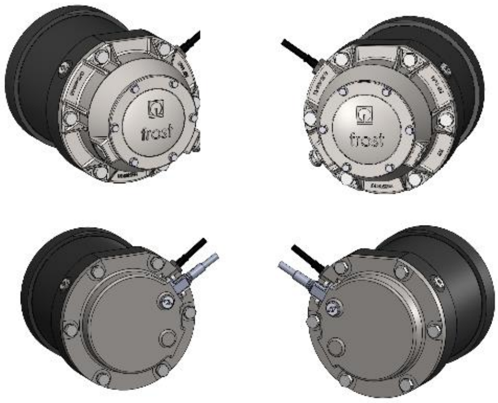

Fig. 12. Axle bearing housings

2.10. Elements of additional equipment

– Flange lubrication system

The vehicle is equipped with an oil lubrication system for the rims of the wheelsets supplied by the DELIMON company, shown in Fig. 13. The system is built on the rolling bogie wheels – the extreme ends of the vehicle. The trailing axle of the end bogies has nozzles on both the left and right side. Lubrication only takes place on the trailing axles in the direction of travel. The system has a sensor for the rotation of the trolley in relation to the box, therefore, when driving in a curve, additional lubrication of the wheel flanges may be activated. Each end bogie has an individual lubricant reservoir with a capacity of 6.5 liters. A plunger metering pump is mounted at the bottom of the tank.

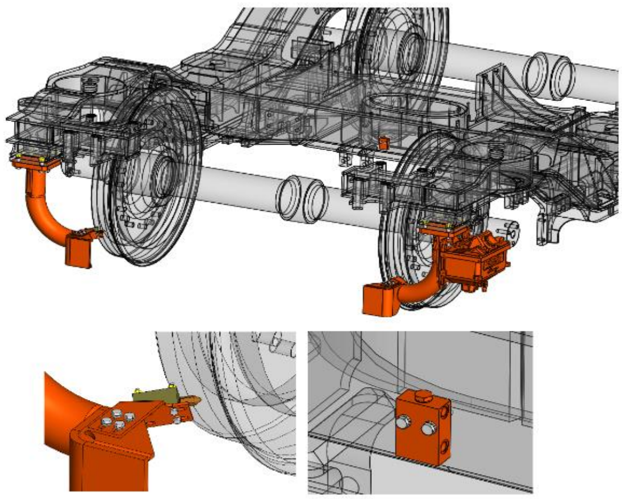

Fig. 13. Flange lubrication system of the 46AN bogie

– Sandblasting system

The vehicle is equipped with sandboxes of the SD1 type (Fig. 14). Each wheel of the driving bogie has a separate sand tank, which is heated by a heater with a thermostat. From each sandbox there is a flexible pipe leading the sand into the immediate vicinity of the wheel-rail contact with the use of a nozzle. The sandbox nozzles are also electrically heated. During normal vehicle operation, the sanders are activated automatically when a slip is detected when braking or starting. The amount of sand discharged from the sandbox depends on the value of the given pressure. The pressure value at the regulator outlet is determined in such a way as to ensure the amount of sand poured out at the level of 400 + 100 g/30 s of work. A sight glass is built into the sandbox reservoirs to assess the sand level. Additionally, the system has a sand level sensor informing the driver about the low sand level.

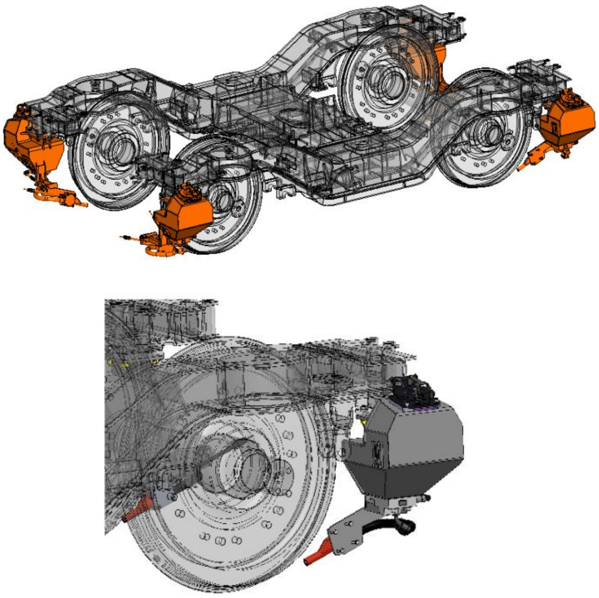

Fig. 14. Sanding system of the 41MN driving bogie

– Arrangement of electric wires on the bogie

In the construction of bogies, we can distinguish two types of electrical installation. The first of them – high-current one, supplies the actuators of devices with a safe voltage of 24 V. These elements include heaters for sand dosing nozzles of the sanding system, the wheel flange lubrication system, and the rail brake system.

The sensors mounted on the bogie constitute a second separate installation. These include sensors related to the braking system (anti-skid sensor), truck diagnostics and the Vehicle Safety System (ETCS).

The entire electrical installation is tight, i.e. all connecting elements and casing pipes are made of elements with a water-tightness class of IP68. In order to ensure the convenience of handling the box-bogie connection, all cables have been connected to a common connector located in the central part of the bogie, both the rolling and the driving bogie. The cable layouts on the bogie in question are shown in Fig. 15.

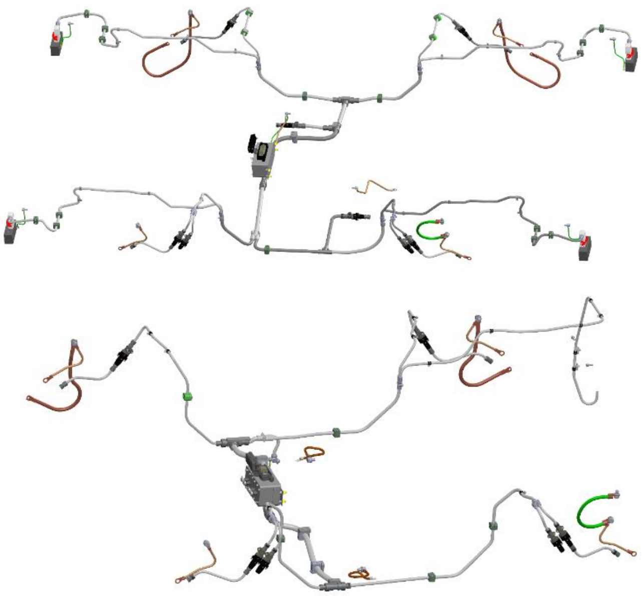

Fig. 15. Electric wiring for the 41MN (above) and 46AN (below) bogies

– Arrangement of pneumatic hoses on the bogie

The system of pneumatic conduits (Fig. 16) is made of stainless pipes, flexible connection conduits and bulkhead couplings. STAUFF clamps were used to attach the pipes to the trolley frame, which in turn

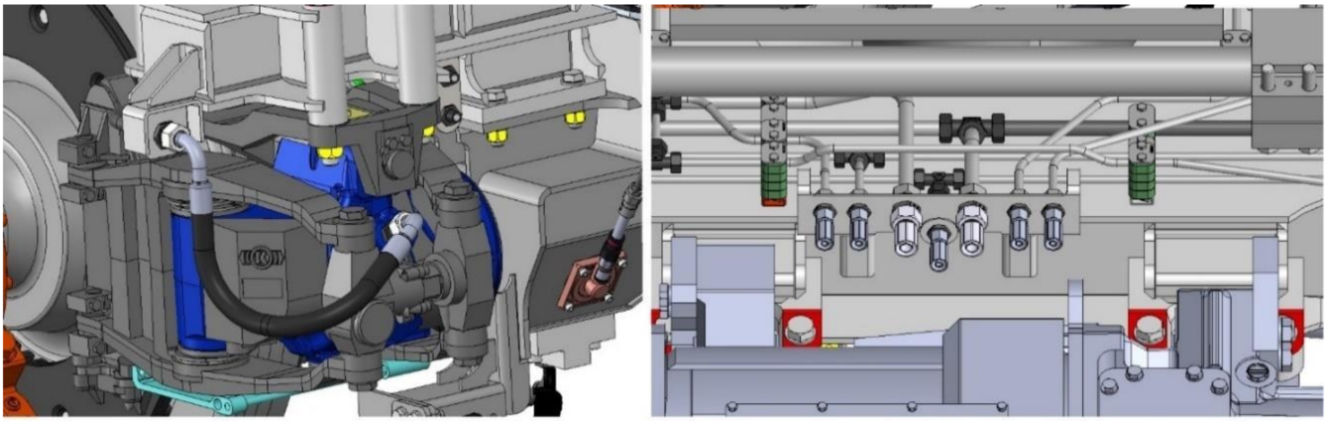

Fig. 16. The system of pneumatic hoses on the 41MN bogie

were screwed to the profiles using system T-nuts, allowing the clamps to move freely along the length of the profile. Pneumatic installation – just like the electric one, it has its connection in the central part of the bogie.

4. Summary

The 41MN and 46AN bogies have been developed for use in the 227M, 228M (FPS Plus) family of vehicles. The applied solutions of the running gear enable driving at a maximum speed of 160 km/h.

The unified structure of the frame allows for its easy adaptation to the installation of both components of the driving and rolling bogies. The basic bogie systems are designed to transfer the loads resulting from the pressure of the wheelset on the track, amounting to 18 tons. The appropriate selection of the primary and secondary suspension as well as the tractive force transmission and wheelsets guiding systems translates into good running properties of the bogies. This allows for a high level of safety, driving comfort and minimization of wheel tread wear. The use of the brake discs in the wheels made it possible to make good use of the space in the central part of the axle for the installation of the drive system.

When defining new development conditions for the designed running gears, one should take into account the criteria that must be met. The criteria should be:

– mechanical compatibility
– electrical compatibility
– pneumatic compatibility
– adequate material strength, analytically confirmed by means of calculation methods
– safety against derailment and dynamics proven by analytical calculation methods.

Nomenclature

ED	electrodynamic brake
EP-B	electro-pneumatic brake
ETCS	European Train Control System
HZT	hybrid traction units
PN	pneumatic combined brake
PS	parking spring brake
S	body roll
TBU	Tapered Bearing Unit
TSI	Technical Specifications for Interoperability
UIC	Union Internationale des Chemins de fe (International union of railways)

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