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TRACTION BOGIE FOR NARROW GAUGE TRAM WITH NON-STANDARD PRIMARY SUSPENSION

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Abstract:
The article describes the research and development of a traction, rotating bogie for a low-floor tram. It draws attention to problems that had to be resolved during development. In the first stage, this non-standard bogie concept was compared with a standard bogie, with Megi rubber silent block suspension. The comparison of the variants resulted in the more appropriate use of the variant with a longitudinal traction motor and with primary suspension and two-wheel guidance by a leaf spring. Its advantage is the possibility of disassembling the entire two-wheel without untying the bogie from the tram. The bogie bolster is somewhat simpler in terms of construction and stress, and its FEM analysis shows a favorable distribution of stresses and deformations. Static tests confirmed the results of FEM calculations. The developed bogie has a smaller wheelbase and weighs about 300 kg less.

Key words:
Rotating bogie, low-floor tram, traction motor, bogie bolster, FEM

1 INTRODUCTION

Urban rolling stock is almost exclusively used for passenger transport. This is conducted either at ground level (level, ground, surface transport) or outside the ground level (underground, subsurface or above-ground transport). Both systems can be combined. Level transport is provided by trams. Their characteristics are electric cars or electric units, dimensionally adapted to the space reserved for tram operation. Inter-level transport is also operated by electric units. They are operated at higher speeds because there is no risk of collision with road traffic, he claims in his publication Heller (2017). Development trends in urban public transport throughout Europe are aimed at solving public transport for people with reduced mobility or for boarding with baby carriages. The solution is low-floor trams and buses (Kalina, 2018).

The bogie is an important part of a rail vehicle and significantly affects its driving characteristics as well as the operating costs of the vehicle itself and the transport route (Hauser, 2019). When designing the tram bogie concept, it is necessary to respect the specifics of the urban railway environment. Authors Lewis and Olofsson (2009) claim that for the geometric position of the track, company internal standards are applied, which are different from one city to another. Other research (Smetanka, Šťastniak and Harušinec, 2019) states that there are curves with a very small radius of approx. 18 meters in the city railway. In interaction with the fixed guidance of the two-wheeler in the longitudinal direction, in the wheel-rail contact there is an increased driving resistance of the vehicle and abrasive wear in the wheel-rail contact (Gerlici, 2017). Another peculiarity of urban railways is the great twisting of the track, or its buckling. The size of the permissible twist is defined by the relevant standard (Ďurkovský and Kubala, 2007).For urban railways, it is advisable to design a bogie concept that completely or partially eliminates the change in the vertical forces of the wheels during driving (Dižo and Blatnicky, 2017).

The development of a traction rotating bogie with non-standard primary suspension by two parallel leaf springs shows one of the possibilities to achieve favorable characteristics of the bogie for passing through an arch. For a narrow gauge, but not only for it, it is necessary to free up space between the wheels for a low floor. Therefore, the two-wheel drive is solved by a longitudinal traction aggregate, outside the bogie frame.

2 METHODS AND METHODOLOGY

The non-standard traction, rotating bogie for a narrow-gauge tram is being developed in cooperation with the University of West Bohemia in Pilsen (ZČU), the RTI workplace, with industrial partners Pragoimex a. s., and VKV s. r. o. Prague as part of the EPSILON program of the Technological Agency of the Czech Republic (TAČR), with the significant support of Krnovskéopraven a strojíren a. s. Krnov (KOS). The bogie development methodology is in accordance with the EN 13749:2011 standard, which is intended for the design of bogie frames for railway applications, including the method of their evaluation.

When verifying the function of the non-standard primary suspension, with two parallel leaf springs within the GAMA program, we found favorable properties of this arrangement. The action of centrifugal force when passing through a curve makes the wheels on the outside of the bogie heavier and the wheels on the inside of the bogie lighter, increases the wheelbase on the outside rail and decreases it on the inside rail, and the wheelset assumes an almost radial position, or at least the angle of attack is reduced. The following Fig. 1 resembles a functional sample for verifying the primary suspension and guidance of the two wheels with a pair of leaf springs and their fastening on the bearing housing of the adapted narrow-gauge two-wheel from DP Liberec-Jablonec.

Fig. 1 *Functional sample of primary suspension with a pair of leaf springs. On the right, a detail of the fastening of the springs on the bearing housing*

3 RESULTS

The interesting results inspired us to design the entire rotating bogie for the narrow-gauge tram. Together with Pragoimex and VKV, ZČU received support from the EPSILON program of the Technology Agency of the Czech Republic, project TH02010553.

3.1 Comparison of a non-standard bogie concept with a standard bogie

One of the first steps was to compare this non-standard bogie concept with standard bogie, with Megi rubber silent block suspension.

We developed two variants: Variant I. (Fig. 2) longitudinally oriented two-wheel drive (Heller, 2016), fully sprung traction assembly, with asynchronous motor and bevel-spur gearbox. The entire unit is fixed on the bogie frame, outside the wheels.

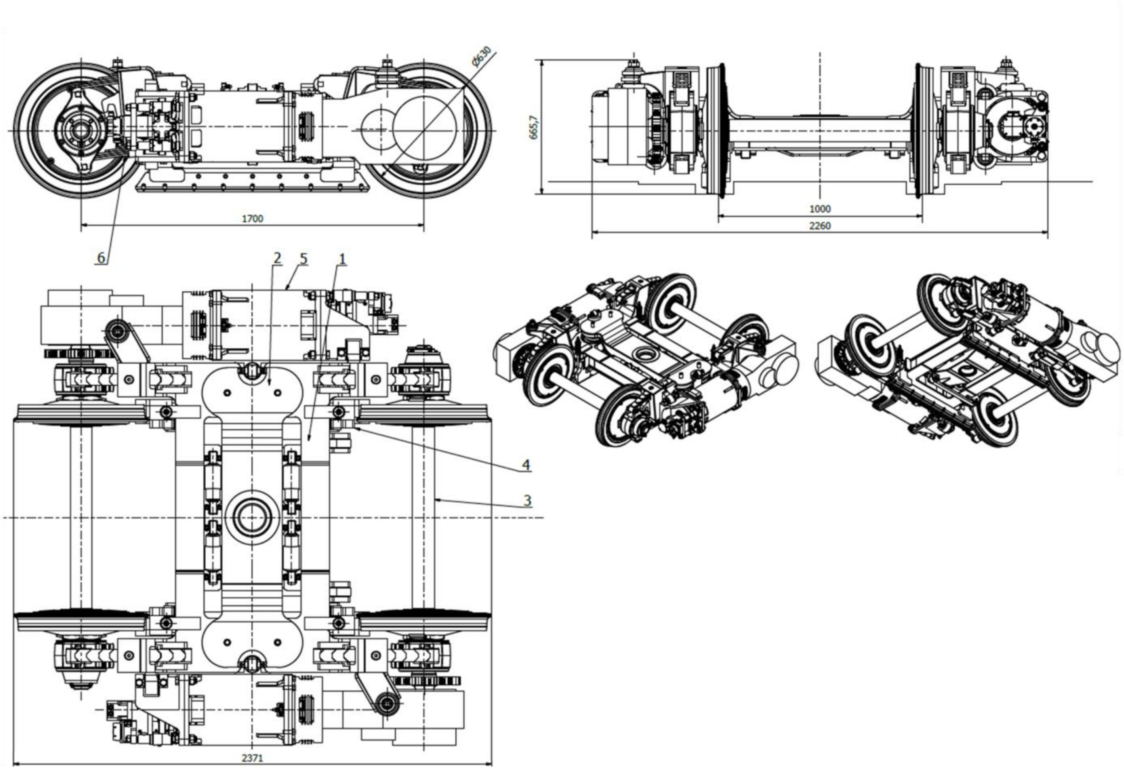

Fig. 2 *Variant I. Traction bogie with longitudinal traction unit: 1 – bogie frame, 2 – bogie bolster, 3 – wheelset, 4 – brake caliper, 5 – traction motor, 6 – leaf spring*

Variant II. (Fig. 3) Traction motor whose axis is parallel to the axis of the wheels. The motor is mounted on the transom. The torque is transmitted via a short joint shaft to a two-stage transmission with spur gears, the transmission is partially sprung.

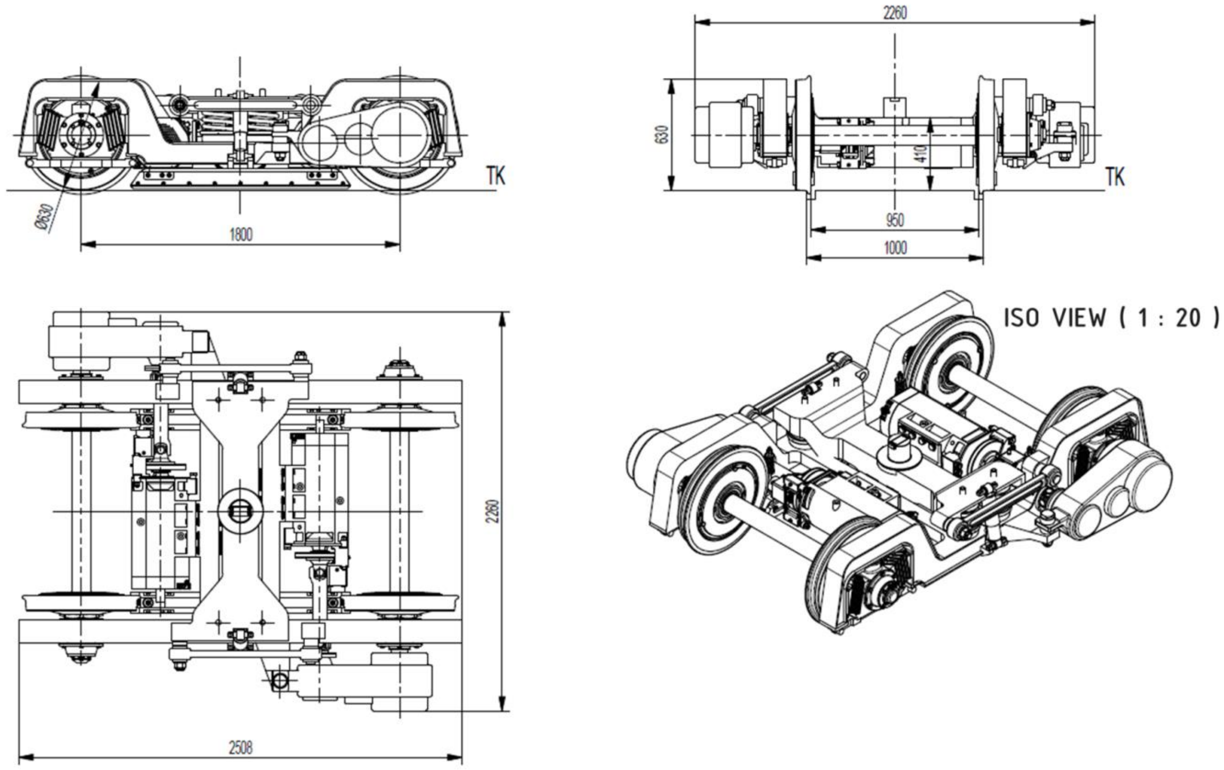

Fig. 3 *Variant II. Traction bogie with motor parallel to the axle*

A comparison of the variants can be found in Table 1. The advantages of variant I, i. e. with a longitudinal traction motor and primary suspension and guidance of the two wheels by means of a leaf spring, are fairly clear from it. The advantage of variant I, in addition to the information in Table. 1 there is also the possibility of disassembling the entire two-wheel without untying the bogie from the tram. The disadvantage of variant II was the larger wheelbase of the bogie, the traction motor is located in the space under the low floor. Variant I was developed up to construction drawings. Production of almost all building structures took place in Krnovské opravny a strojírny a. s.

The bogie bolster (Fig. 4 and Fig. 9) is somewhat simpler in terms of construction and stress, and its FEM analysis Ráž (2018) shows a favorable distribution of stress and deformations. Static tests confirmed the results of FEM calculations. The bogie bolster, whose weight is 140 kg, is placed on a secondary suspension. Longitudinal forces between the frame and the bogie bolster are transmitted by the rods under the bogie bolster and the frame.

The springs (Fig. 8) of the primary suspension are fixed on the bearing box in the frame using pins and rubber silent blocks in the eyes of the spring. The elastic belt is stored in a bed on the bogie frame. The springs were manufactured by Grewis. The upper and lower springs each have their own supporting place. The leaf spring has internal damping, it does not need a damper.

***Tab. 1** Comparison of bogie variants*

Variant I – longitudinal motor		**Variant II – motor parallel to the axle**	
Motor Suspension with sprung hinges longitudinally from outside of the frame	1	Motor Suspension at the frame transom, unsprung	3
Gearbox – from outside of the frame, sprung hinges, bevel-spur	2	Gearbox – from outside of the frame, unsprung, spur	4
Connection of motor and gearbox – flexible shaft coupling	2	Connection of motor and gearbox – joint (Cardan shaft)	4
Connection of gearbox and axle – balance shaft coupling	3	Connection of gearbox and axle – interference fit	3
Primary suspension – leaf springs	2	Primary suspension – Megi inclined rubber-metal springs	3
Secondary coil spring suspension, lever arm shock absorber	1	Secondary coil spring suspension, hydraulic shock absorber	1
Longitudinal forces transmission – traction rods under the bogie bolster	2	Longitudinal forces transmission – traction rods from outside of the bogie frame	2
Bogie frame welded	2	Bogie frame welded	2
Bogie wheelbase 1700 mm	1	Bogie wheelbase 1800 mm	5
Bogie frame weight 460 kg	1	Bogie frame weight 590 kg	4
Sum	**17**	**Sum**	**31**

Legend: Point rating 1– best, 5– worst

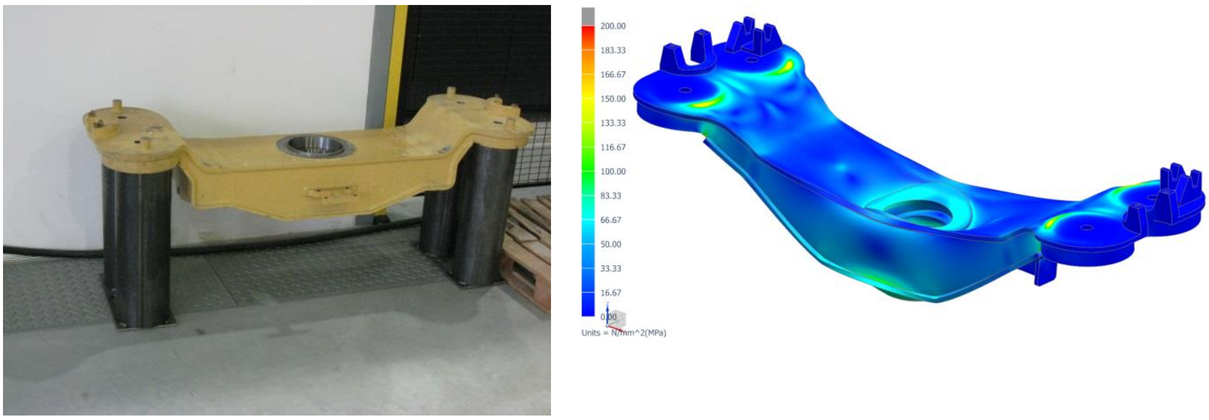

***Fig. 4** On the left is a bogie bolster ready for testing, on the right is an FEM analysis*

The secondary suspension is formed by coil springs, it is inserted between the bogie frame and the bogie bolster. Vertical damping is provided by lever arm shock absorber from STOS Oslavany.

The drive unit is located outside the two wheels, it consists of a 70 kW traction motor (Fig. 5), a bevel gearbox, a coupling between the gearbox and the two wheels. A shaft emerges from the traction motor on both sides (Heller, 2016). At one end it is connected by a coupling to the gearbox, at the other end a disc brake is mounted. The traction motor has flanges on both ends, one is connected via an intermediate piece to the gearbox, the other has a bracket for mounting on the bogie frame. The power unit is therefore attached to the bogie frame at 3 points, one is on the gearbox, the other two points are on the console near the brake. Traction motor tests were successful.

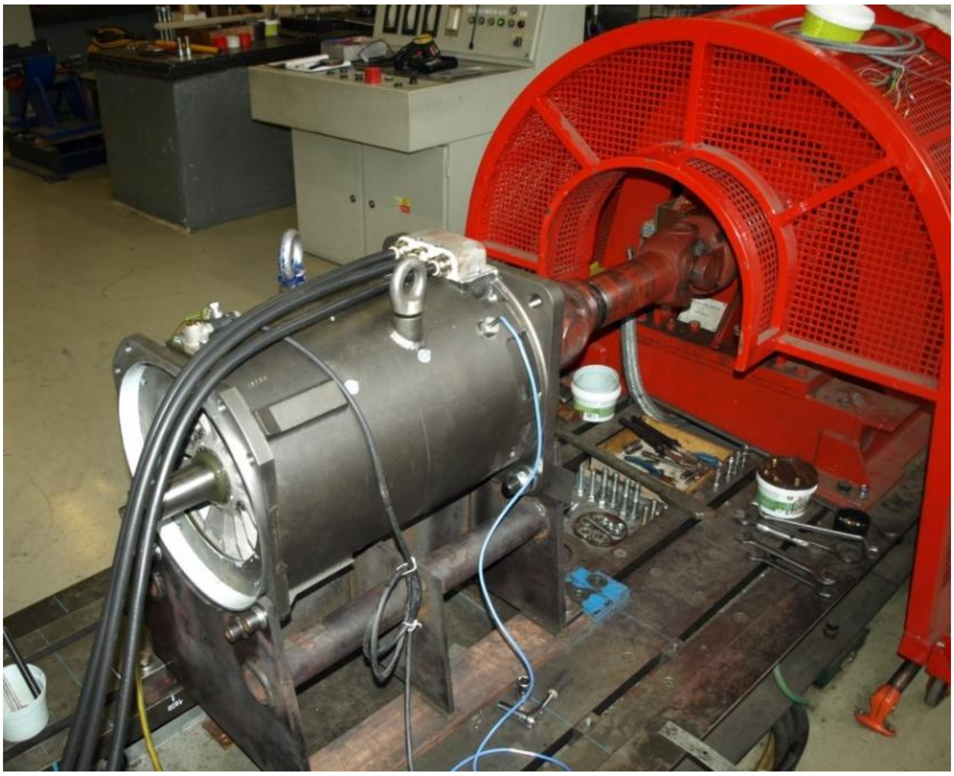

Fig. 5 *Traction motor test on the test bench*

The following Fig. 6 shows a general view of the bogie with all structural structures.

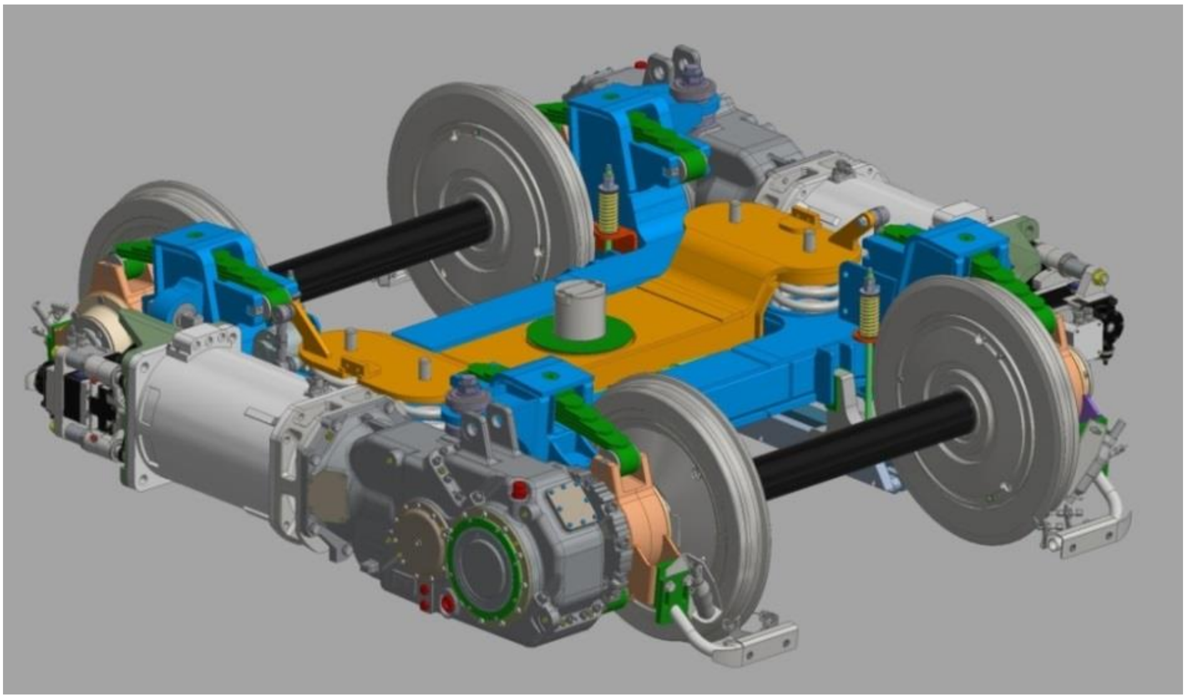

Fig. 6 *General view of the bogie from the gearbox side*

For the tests (Fig. 7), we replaced the leaf springs with rigid beams and the wheels with bearing housings with a support device.

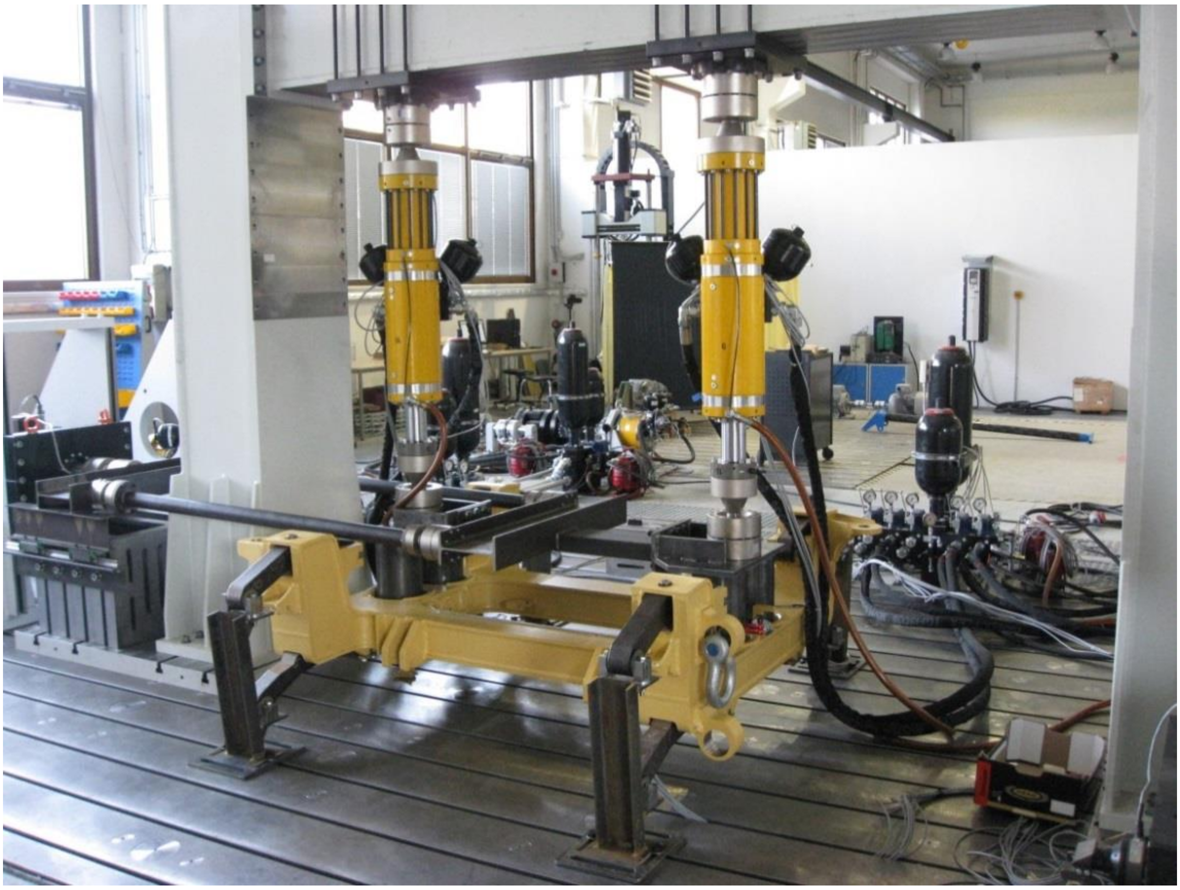

Fig. 7 *Bogie frame on the test stand for fatigue strength testing*

Vertical forces are introduced by two hydraulic cylinders. Transverse forces by one horizontal cylinder. The test is carried out according to ČSN EN 13 749. The tests of leaf springs (Fig. 8) were interesting, especially when compared with the test of a rubber silent block for the same purpose.

Fig. 8 *Leaf springs*

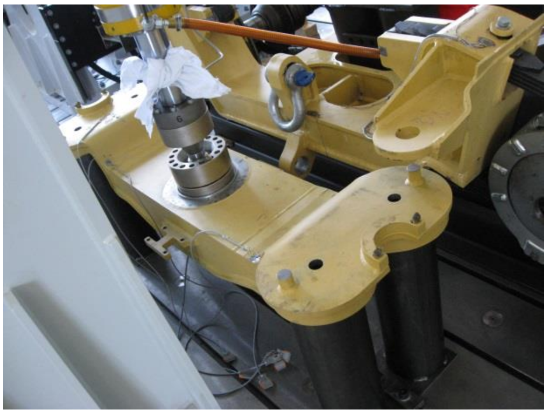

Fig. 9 *Bogie bolster test*

The 60x10 mm sheet spring was on the previous functional sample. For the current bogie, we had to increase the rigidity, by increasing the dimensions of the sheet to 60x11 mm, in order to reduce the vertical movements of the frame in relation to the two wheels, due to the coupling between the motor and the two wheels. This coupling needs less than 15 mm of movement to pass through the hole in the gear wheel and gearbox.

Fig. 10 shows the stiffness of leaf springs and a comparison with the rubber spring used in Astra trams. The theory says that the rubber spring springs and dampens. The graph shows that it springs but undampens. On the other hand, leaf springs dampens. Also composite springs of similar dimensions as a leaf spring but it undampens as well.

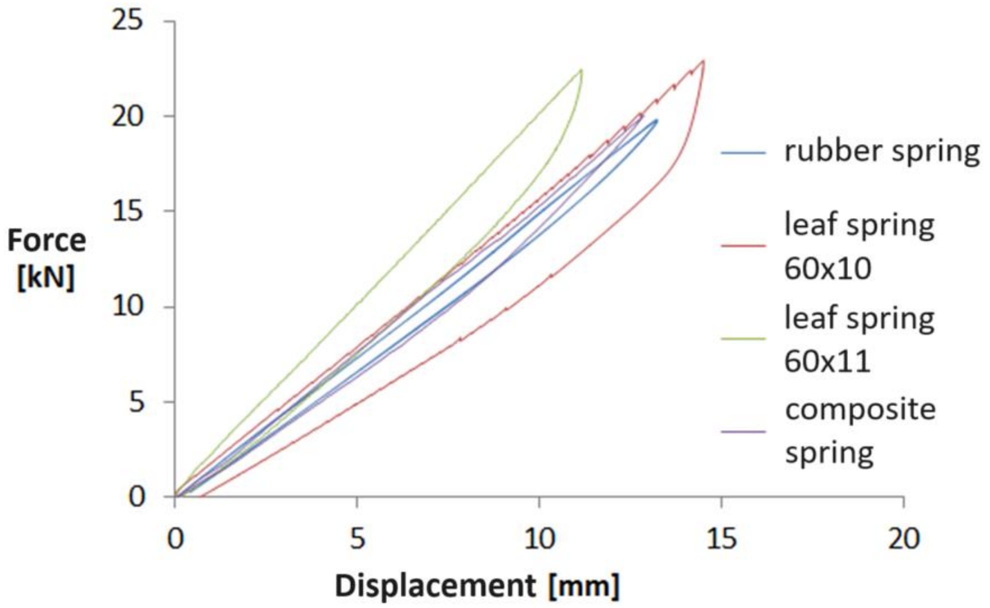

Fig. 10 *Measured characteristics of leaf springs and rubber spring*

4 CONCLUSIONS

The article shows the solution procedure and partial results of a non-standard rotating bogie for a narrow-gauge tram vehicle. It uses previously acquired experience with suspension with leaf springs, which allow partially radial positioning of wheels in an arc under the action of centrifugal force. The advantages of the bogie will be a smaller wheelbase and the associated lower weight of about 300 kg.

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