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BOGIES FOR HIGHER SPEEDS HAVING A SHORT WHEEL BASE

Для скорочення часу поїздок необхідне збільшення швидкостей руху екіпажів. Існуючі швидкісні поїзди мають базу візка 3 м і більше. Величина бази впливає не тільки на стійкість руху системи, але і на вагу рами візка. Зменшення бази можливо при використанні систем активного підвішування, а також при використанні конструкцій з міжосьовими зв'язками.

Для сокращения времени поездок необходимо увеличение скоростей движения экипажей. Существующие скоростные поезда имеют базу тележки 3 м и более. Величина базы оказывает существенное влияние не только на устойчивость движения системы, но и на вес рамы тележки. Уменьшение базы возможно при использовании систем активного подвешивания, а также при использовании конструкций с межосевыми связями.

The reduce drive time it is necessary to increase the speed of trains. Modern high speed trains have the 3-metre bogie base and an even smaller one. The base size influences significantly not only the system movement stability but the bogie frame weight as well. The base size reduction is possible with the use of the active suspension system and with the use of inter axle link construction as well.

Introduction

It is generally assumed that for rail vehicles with passive suspension systems the maximum operating speed is limited to about 300 km/h and that active suspension systems are required if higher train speeds will become practicable [1]. The analysis given below for the ‘Manchester bench mark’ bogie confirms that this assumption is basically correct for the conventional bogie designs presently being used for high speed trains. Such conventional bogies have frame guided wheelsets and their hunting stability is mainly controlled by three suspension parameters, namely the stiffness of the longitudinal and lateral journal box suspension and the rotational resistance between bogie frame and vehicle body (yaw dampers). The dynamic analysis of such bogies given below also shows that the operating speed requirements of modern high speed trains can be met by such conventional bogies only if relatively long wheel bases are used.

The use of unconventional bogie designs having inter-axle linkages for the guidance (Fig. 1, left) of the wheelsets [2] is at the present time mainly limited to higher axle load freight car applications where advantage is taken of the self-steering ability of wheelsets having profiled wheels for better curving performance and reduced wheel and rail wear [3]. However, in this paper it will be shown that such unconventional bogies also have a superior high speed potential than conventional bogies if in addition to the inter-axle linkages a so-called set gear, is provided. This set gear is a type of Watt’s linkage which is fitted between the two wheelsets and the bogie frame and firmly couples the bogie frame longitudinally to the center of yaw of the wheelsets (Fig. 1, right). The analysis shows that bogies having such double linkages and a rotational resistance between the bogie frame and vehicle body do not only have a higher hunting stability than the conventional bogie designs presently being used for high speed trains but also maintain such superior stability behavior for shorter wheel bases.

1. Vehicle model

Comparison of the conventional and unconventional design is based on vehicle 1 of the Manchester Benchmark [2] with the modification of additional yaw dampers. Mass of the car body is about 32 t at a length of 24 m. The 2 – axle bogie with wheelbase 2.6 m is designed with very stiff longitudinal primary stiffness (31.4 kN/mm) and moderate lateral primary stiffness (3.9 kN/mm) to fulfill requirements of stability and comfort. Stability of this vehicle allows to run speeds up to 250 km/h if yaw dampers are introduced. Damping of the yaw dampers is 400 kNs/m with in series stiffness of 8000 kN/m.

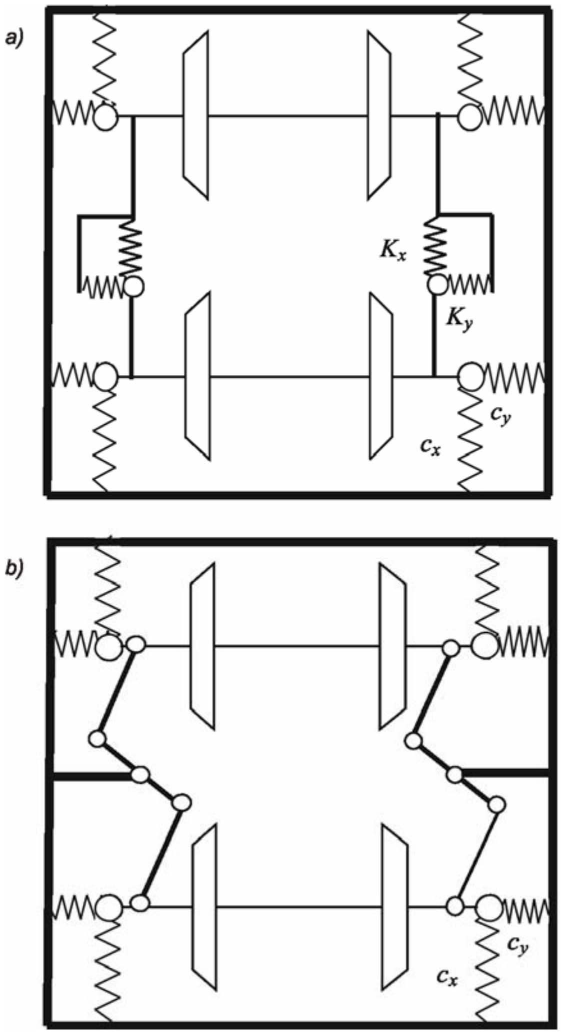

Fig. 1. Inter-axle linkages "radial arm" (a) and "set gear" (b)

The unconventional bogie is mounted below the same car body. Bogie center distance is the same. But wheel base is only 1.8 m. We have chosen this small wheel base to demonstrate the advantage of the unconventional design. Bogies for high speed trains are designed with wheel base not less than 2.6 m to fulfill stability requirements. Primary stiffness is 4 kN/mm for longitudinal and lateral stiffness. Lateral stiffness is modeled also with a progressive part. Progressive stiffness is starting from zero to the value of 4 kN/mm for the 1st three millimeters of relative lateral displacement of bogie frame to the axle box . Such a progressive stiffness can be achieved by a wedge type spring base.

The first question which arises is: What do we get using the additional device "set gear" compared to a bogie with only radial arm inter axle linkage.

Analysis of this type of a bogie is based on simulation with MBS simulation tool MEDYNA. Results are presented for stability of the vehicle for linear and non-linear wheel rail contact. Vehicle safety, track loading and riding comfort is shown running on straight track and negotiating a curve. Track quality is of quality QN2, worst quality allowed according regulations of UIC to maintain traffic.

Two bogie vehicle models are analyzed, both having yaw dampers:

Conventional bogie design with high stiffness for longitudinal and moderate stiffness for lateral primary suspension, wheel base 2.6 m.

Unconventional design with moderate stiffness for primary suspension, direct inter axle linkage by radial arm and additional linkage by "set gear", wheel base 1.8 m.

Fig.2 shows comparison of critical speed of the vehicle having bogies with radial arm design (lower mesh) and radial arm with set gear (upper mesh). Yaw dampers and all other vehicle parameter are the same. The wheel base in this comparison is 2.6 m for both models. The model with radial arm includes the conventional design. Conventional bogie has low shear stiffness and high bending stiffness.

Dependency of critical speed on bending and shear stiffness parameters is less for the design with set gear and radial arm and critical speed is much higher. This result of the linear stability analysis indicates, it is worth while to analyze influence of set gear together with radial arm on dynamics of a bogie vehicle.

2. Stability analysis

Stability is computed using quasi-linear wheel rail contact model and non linear wheel–rail contact model with flexible contact. Wheel profiles have profile shape S1002 and rails have profile UIC60 with inclination 1/40 and gauge 1435 mm.

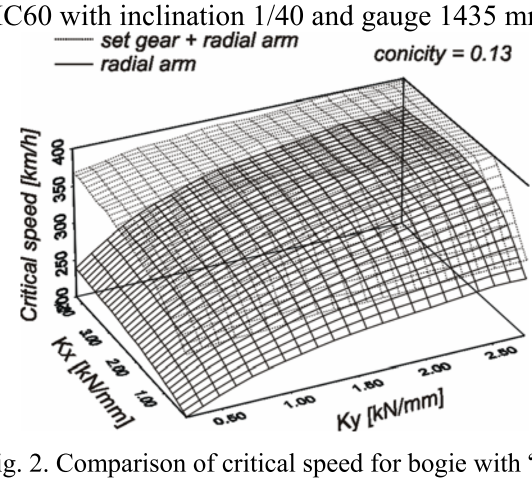

Fig. 2. Comparison of critical speed for bogie with "set gear + radial arm" and "radial arm" as function of bending and shear stiffness

2.1 Stability with linear wheel rail contact model

Influence of conicity is analyzed with the quasi-linear model (Fig. 3). Both designs show the very common dependency: decreasing critical speed for increasing conicity. Unconventional design allows a remarkably higher critical speed for all conicities. Critical speed is above 250 km/h for conicities up to 0.6. Measurements of conicities show that even values of 1 on real track in Europe are possible. From this point of view it is essential to have a design which is capable to run stable also for high conicities.

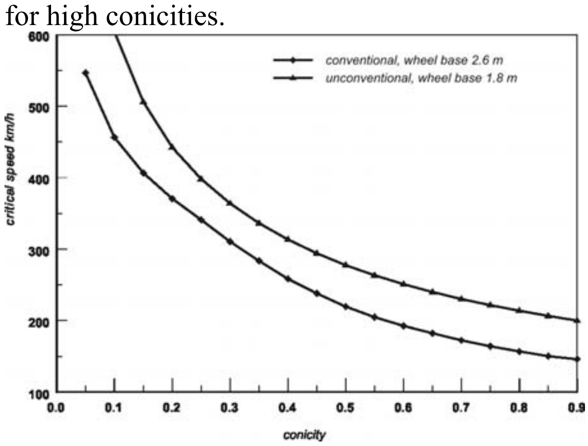

Fig. 3. Critical speed as function of conicity

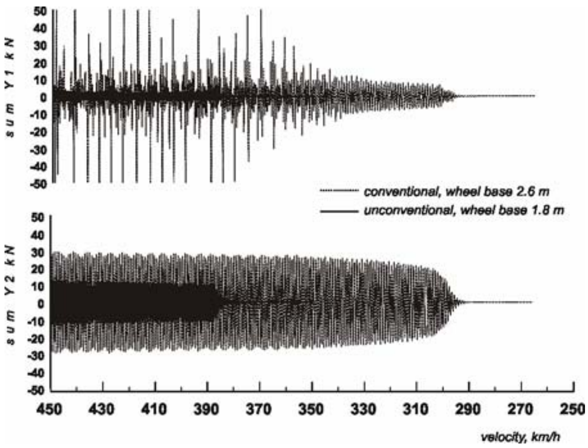

Fig. 4. Limit cycle, sum of lateral forces as function of decreasing velocity, progressive lateral primary stiffness for unconventional bogie

2.2 Stability with non linear wheel rail contact model

Stability analysis of railway vehicles show limit cycles. Amplitudes of movements of wheelsets depend on velocity. Depending on the number of wheelsets a different number of movement configurations appear with different limit cycles. For safety reasons it is essential to compute stability of the mode with the lowest critical speed. Simulation results of limit cycle analysis tools [4] show, that very often an unstable mode with amplitudes near the flange has a lower speed than critical speed computed with a linearized model. Hunting modes with flanging of wheels very likely lead to the lowest critical speed when such a limit cycle dies out with speed reduction. In MEDYNA critical speed of a vehicle is computed looking for the velocity hunting is dying out. As speed reduction by braking would change results, reduction of speed is done synchronizing velocity of wheels and rotational speed. No longitudinal creep forces will arise due to speed reduction. In Fig. 4 stability of the two models is compared showing sum of lateral wheel-rail contact force as function of velocity. Velocity of both models was 1st increased starting at 350 km/h until hunting with flange contact occurred and than decreased again. Vehicle model with conventional bogie design shows hunting movements until velocity is below 290 km/h. With unconventional design this happens at about 390 km/h.

This high critical speed we get for unconventional bogie only with progressive stiffness of primary suspension.

Unconventional bogie with progressive lateral primary stiffness (Fig. 5) is running for speeds between 450 and 390 km/h with nearly the same lateral amplitudes as those of the conventional bogie but with higher frequency of hunting and smaller sum of lateral forces.

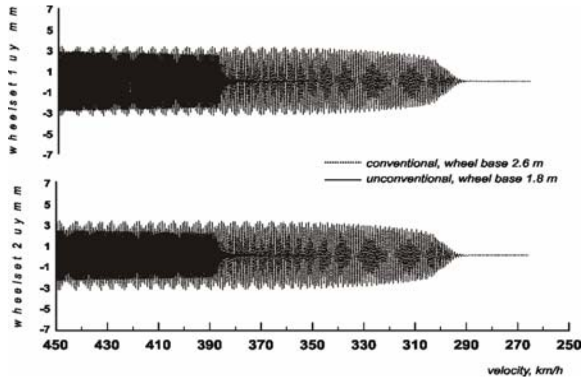

Fig. 5. Limit cycle, lateral displacement as function of decreasing velocity, progressive lateral primary stiffness for unconventional bogie

3. Quasi-stationary curving

Radii of curves are varied between 20.000 m and 610 m. Cant deficiency or uncompensated lateral acceleration follows a linear function from zero for straight track to 1 m/s2 for the curve with 610 m radius. In Fig. 6 wear numbers are compared. Wear number is defined as scalar product of co-ordinates of tangential contact force and normalized creepages. Dimension therefore is Newton. Wear number of leading wheelsets of unconventional bogie are about 50 % of those of the conventional bogie. Wear numbers of trailing wheelsets are approximately the same. Lifetime for wheelsets of unconventional bogie would be higher than those of conventional bogie from wear point of view.

For both models sum of lateral wheel forces (Fig. 7) of trailing wheelsets are higher than forces of leading wheelsets. For the unconventional bogie maximal value of force and difference between leading and trailing wheelset is bigger. This is due to the improvement in radial alignment. But lateral forces are well below the limit defined for the sum of quasi stationary lateral force of 60 kN which also is a result of improved steering in curves.

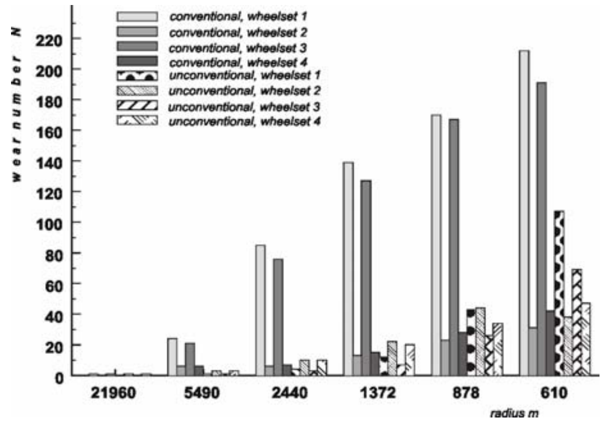

Fig. 6. Wear number as function of curve radius, linear increasing resultant lateral acceleration to 1 m/s^2 at 610 m

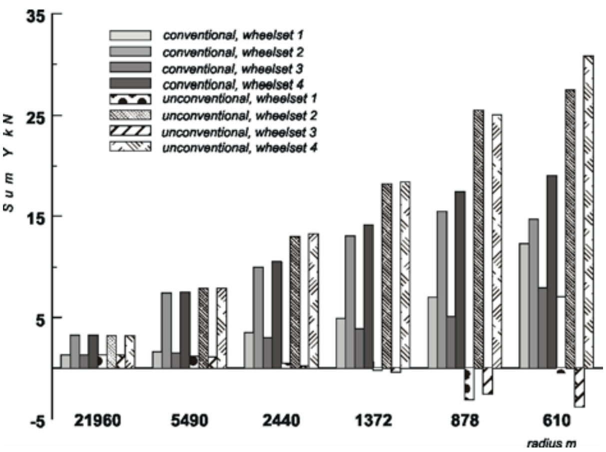

Fig. 7. Sum of lateral wheelset force as function of curve radius, linear increasing resultant lateral acceleration to 1 m/s2 at 610 m

4. Track loading, safety and ride comfort

Analysis of track loading, safety and ride comfort of the two models is based on conventions for the testing of vehicles described in UIC 518.

4.1 Track irregularities

Track quality is of category QN2, the worst quality allowed for save running without line speed reduction. Histories of displacements of left and right rail are based on power spectra. Fig. 8 shows lateral and vertical displacements of left and right rail and Fig. 9 gives statistical data, mean value, standard deviation, minimal and maximal values. As power spectra for quality definition are defined within a frequency range velocity must be taken into account, when computing histories of irregularities. Velocity used for the definition is 350 km/h.

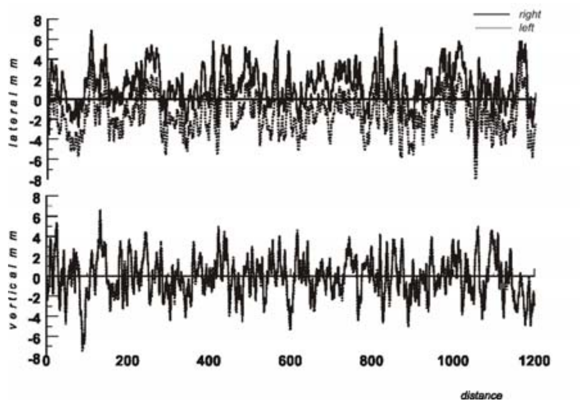

Fig. 8. History of rail irregularities, quality QN2 for 350 km/h

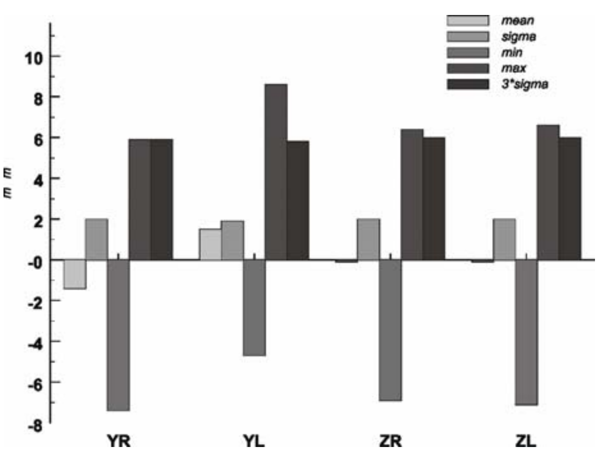

Fig. 9. Statistical values of rail irregularities, quality QN2 for 350 km/h

4.2. Simulation on straight track

The vehicle models are running with 350 km/h on track of 1200 m length having track quality QN2. Data of output signals are recorded in MEDYNA as shifting mean values in equidistant track steps. Output step size is 0.5 m. shifting mean value 0.5 m. In Fig. 10 sum of lateral forces of each wheelset is shown.

Maximum values of ratio of lateral to vertical wheel force (Fig. 11) are not really different for the two designs. The greater differences for two of the wheels are due to single events on track.

The higher values of the model with unconventional bogie for maximal acceleration on car body floor (Fig. 12) in observer points in front and rear position are due to the shorter wheel base. The bogie is more sensible to irregularities with shorter wavelength and this means higher accelerations.

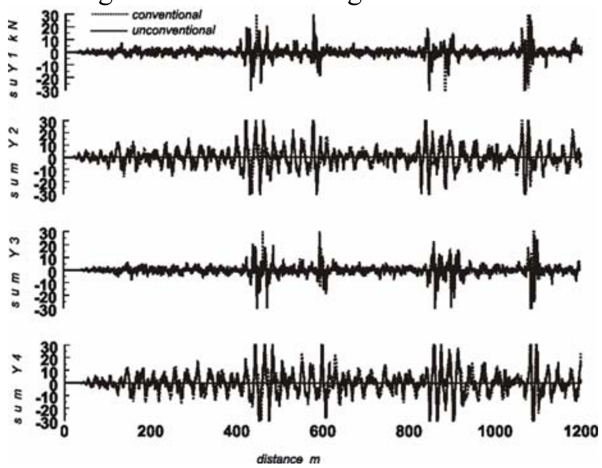

Fig. 10. Track loading: history of sum of lateral forces on straight track, speed 350 km/h, track quality QN2

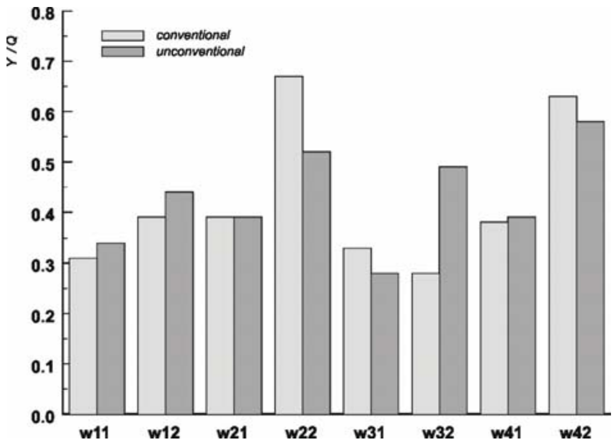

Fig. 11. Safety, maximal values of ratio of lateral to vertical force, speed 350 km/h, track quality QN2

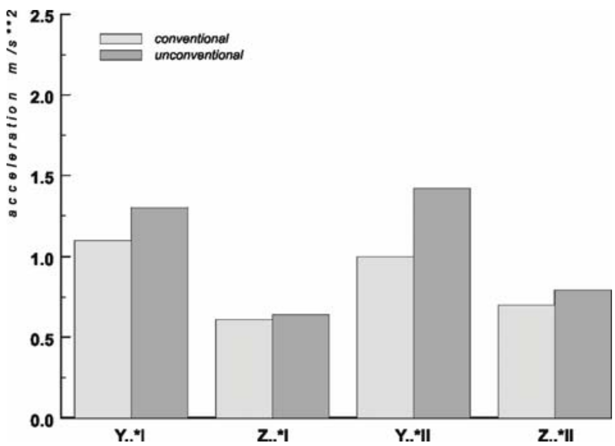

Fig. 12. Ride quality, maximal values of car body accelerations front and rear, speed 350 km/h, track quality QN2

4.3. Simulation of curving

Performance in curving is shown for a curve with radius of 2500 m, cant of 150 mm and length of transition 200 m. The vehicle model is running with 250 km/h, which means cant deficiency is 135 mm.

Sum of lateral wheel forces in Fig. 13 show again, that forces with unconventional bogie are a bit higher than with conventional bogie but still very much below the limiting forces of 60 kN. For both bogies forces on leading axle are smaller than on trailing axle.

Acceleration on car body (Fig. 14) again show the influence of the shorter wheel base. They are quite high especially in lateral direction. This is due to the poor track quality, which should not be the standard for railway vehicles running with 250 km/h on curved track.

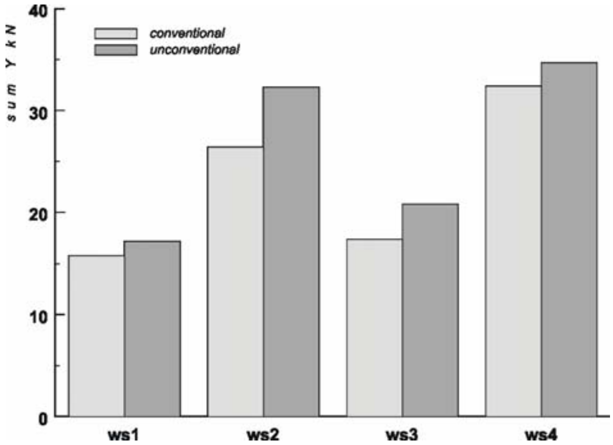

Fig. 13. Sum of lateral wheelset force negotiating a curve with 2500 m radius at 250 km/h, unbalanced acceleration 0.9 m/s²

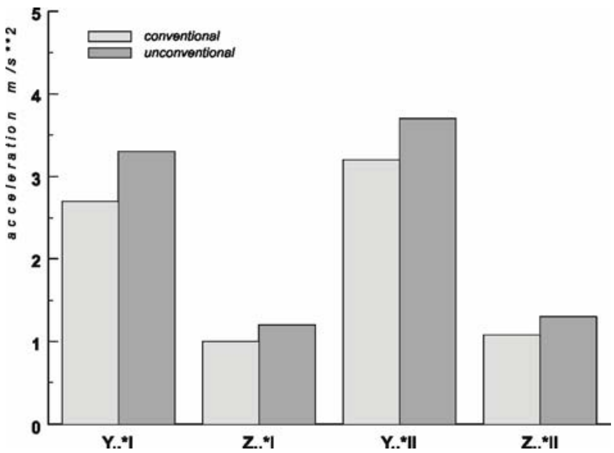

Fig. 14. car body accelerations negotiating a curve with 2500 m radius at 250 km/h, unbalanced acceleration 0.9 m/s²

Conclusions

The analysis of the hunting stability of railway vehicles shows that the operating speed of vehicles having passive suspension system can be raised to speeds considerably higher than 300 km/h through the use of unconventional bogie designs having inter-axle linkages, set gear, progressive part in lateral primary stiffness and yaw dampers.

Unconventional bogie design using radial arm, set gear, progressive primary stiffness and yaw dampers, offer the opportunity to develop bogies with shorter wheel base for speeds which are thought only mechatronic systems would be able to overcome stability and curving problems.

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