Resource efficient regional train facilitated by single-axle running gears

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ABSTRACT

Regional railway lines with lower usage or part of secondary networks play a vital role in serving regions and as feeders for passenger and freight traffic for the main/core network. These railway lines need to be renewed to make them economically and environmentally sustainable and this is the aim of FutuRe – a project supported by the Europe's Rail Joint Undertaking. Research is conducted in several areas, like traffic management, train positioning, automatic train control, wayside assets, multi-modal travelling, and the vehicle itself, where the propulsion system and the running gear are key research areas. Low weight and cost are crucial aspects for a resource-efficient regional train. Running gears make up a significant part of the weight of a railway vehicle and use of single axle running gears instead of conventional two-axle bogies would reduce the weight and cost. Single axle running gears have been used for rail vehicles from the beginning. Most of the applications have been for freight service where performance has been less important than the acquisition cost. In FutuRe, it is proposed that single axle gears should be used for a two-axle regional train and that the shortcomings of such a simple design should be mitigated through low force active suspensions. Two types of active suspensions are proposed, an active vertical dynamic suspension to ensure good vibration comfort and an active wheelset steering to ensure good curving performance. The solutions are presented together with early simulation results. The impact on Key Performance Indicators used in FutuRe shows that the proposed vehicle will have lower energy consumption, generate less external noise and require less maintenance compared to the regional train offered by the market today.

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1. INTRODUCTION

Regional railways (lines with lower usage or secondary network) play an important role not only in serving European regions, but also as feeders for passenger and freight traffic for the main/core network. Therefore, they have an essential function as an environmentally friendly mode of transport and are an enabler for increasing the transport performance of railways. Unfortunately, many of these routes were abandoned in the past – mainly due to high costs. Therefore, these rail lines need to be revitalized or even renewed to make them economically, socially, environmentally sustainable and meeting current customer needs and challenges. To achieve these ambitious goals, a novel approach is necessary, which is the focus of the FutuRe project (FP6) from the family of the Europe's Rail Joint Undertaking research and innovation activities. The activities are set up in several areas, but is here limited to the running gear, which is an enabler for weight, cost and energy consumption reduction. FutuRe has created a state-of-art report on present small size regional trains [1].

A selection of key requirements for the regional vehicle is given in Table 1 and a visual impression in Figure 1(right).

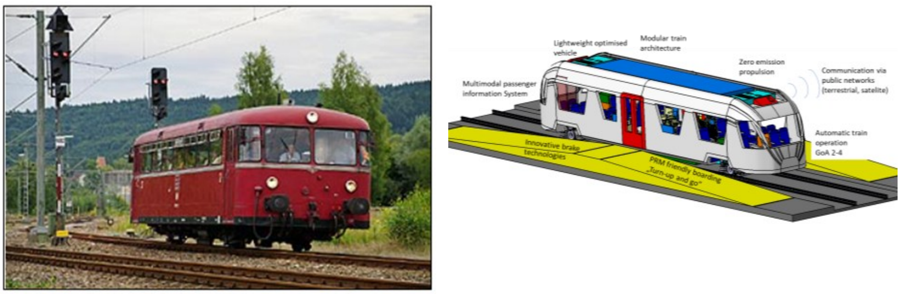

Figure 1: German rail bus from the 1950s (left), The FutuRe vehicle (right) [1]

Table 1: Key requirements for the FutuRe regional vehicle

Requirement	Value	Comment
Loading gauge	G1	European interoperable gauge
Number of passengers	Max. 100 (standees incl.)	Larger vehicles are commercially available
Platform height	550 mm	Level boarding should be offered
Vehicle length	16 m	
Maximum axle load	16 t	Most regional lines allow this axle load
Maximum speed	120 km/h	
Energy source	Battery and hydrogen	Hydrogen for range extension
Service brake	Regenerative	
Emergency brake	Mechanical	
Driving	Remote / automatic	No driver space
TSI compliance [1)]	Deviations	Strength, crashworthiness, and interior climate

1) Technical Specification for Interoperability (TSI) is a set of requirements that must be fulfilled to ensure that the vehicles are interoperable on the infrastructure complying with the specifications. This is strictly not needed for regional lines, but a noncompliance may impose restrictions when run on mainlines.

Single axle running gears have been used for rail vehicles from the beginning, Figure 1 (left). Most of the applications have been for freight service where performance has been less important than the acquisition cost. In the

Shift2Rail project Run2Rail an innovative metro vehicle with single axle running gear and one suspension step is proposed, (Shift2Rail in [2]). Two types of active suspensions were introduced to overcome the shortcomings with such a simple design, an active dynamic suspension to ensure good vibration comfort and an active wheelset steering to ensure good curving performance. In FutuRe, it is proposed that single axle gears should be used for a two-axle regional train and that the shortcomings of such a simple design should be mitigated through low force active suspensions based on electro-dynamic technology. The further intention is to design a vehicle without a compressed air system, hence the passive suspension is foreseen to be a simple coil spring. The expectations with the proposed design are that both investment and maintenance costs will be reduced, which significantly improves the business case for introduction of active suspension in rail vehicles. The impact is evaluated for a set of key performance indicators (KPIs).

2. CONCEPTS OF ACTIVE SUSPENSIONS

2.1 BASIC CONCEPTS

Railway vehicle suspensions are complicated systems aiming at achieving different functions, active suspension technologies with different functions and configurations have been developed in various forms (Goodall et al. in [3] and Fu et al. in [4]). For a passive suspension, stiffness and damping parameters define the dynamic response of a system. The external excitations of the vehicle suspension system include deterministic (track layout) and stochastic (track irregularity) excitations in different frequency ranges. Therefore, the design of a passive suspension becomes a compromise for different operating conditions. In contrast, an active suspension can provide variable suspension parameters by utilization of sensors, controller, and actuators, Figure 2.

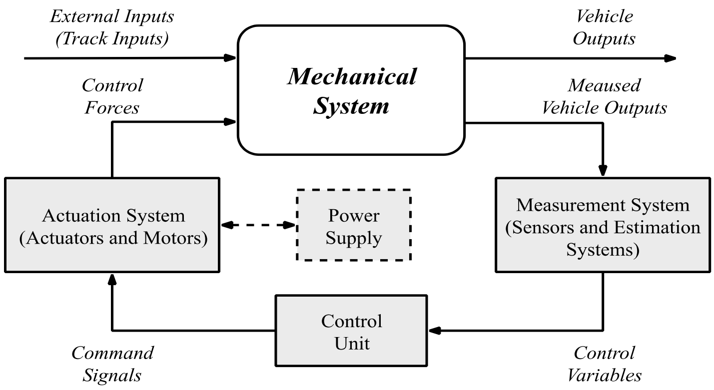

Figure 2: Generic workflow of an active suspension [4]

2.2 ACTIVE SUSPENSION FOR RIDE COMFORT

For FutuRe, active suspension is judged necessary to receive a proper ride comfort. Different approaches are possible to actively improve passenger comfort (Fu et al. in [4]). Among those, a distinction between semi-active and active suspension may be done. Semi-active suspensions could be an option when the initial comfort of the vehicle is sufficiently close to an acceptable limit. However, when the improvement required by the active system is large, fully active systems must be applied. In these cases, the actuators generally replace standard dampers (Pacchioni et al. in [5] and Qazizadeh et al. in [6]). For the two-axle vehicle the latter is to be considered as the comfort with passive suspension is far away from the limit 0.25 m/s^2 for a comfortable ride according to the EN12299 standard [7]. In terms of control strategies, modal sky-hook control, being among one of the most simple and effective strategies, is applied, where the actuator replaces the passive damper and fictive sky-hook is created by integrating body acceleration and using it as force reference to actuator, Figure 3(left).

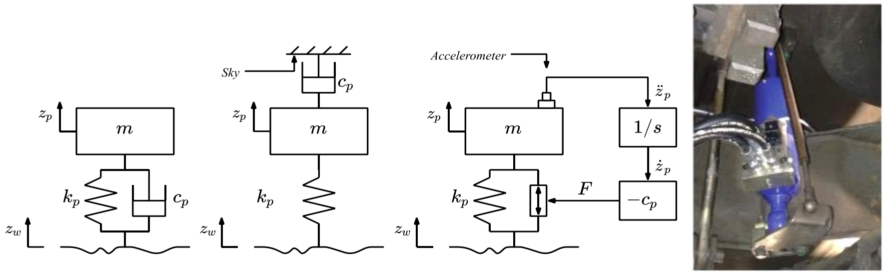

Figure 3: Sky-hook control (left) [4], actuator used in field test (right) [6]

The sky-hook principle has been implemented in field tests, Figure 3 (right) (Qazizadeh et al. in [6] and Sugahara et al. in [8]) as well as on in-service trains. More refined principles may bring benefits, but the sky-hook principle remains the first choice and was used in Run2Rail as well. For FutuRe, the sky-hook will be the starting point together with an electro-dynamic actuator that takes the place of the passive damper.

2.3 WHEELSET STEERING FOR CURVING PERFORMANCE

For FutuRe, active wheelset steering is judged necessary to give proper curving performance. The same judgment was made in Run2Rail and the wheelset steering actuator was set in parallel to the passive wheelset guidance, Figure 4 (left). The main reason was that the safety cases were easier to validate as the passive wheelset guidance ensures safety provided that the maximum actuator force is limited. The actuator was designed to include the passive wheelset guidance to simplify installation. The actuator was tested in the supplier's test bench to validate the performance, Figure 5 (left).

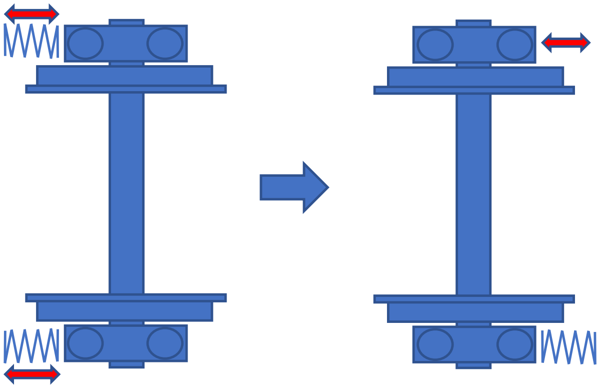

Figure 4: Possible actuator locations in relation to the passive wheelset guidance

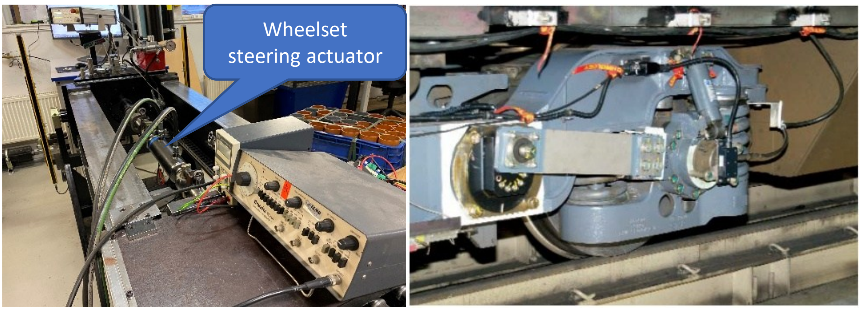

Figure 5: Run2Rail wheelset steering actuator in test bench (left), Bombardier wheelset steering in on-track test (right) [9]

In FutuRe, replacement of passive wheelset guidance with an actuator is studied as it expected to bring further performance benefits, Figure 4(right). A similar setup was designed and tested on track by Bombardier in the Regina 250 test train (Schneider in [9]). The Regina 250 had bogies with a rotating electro-dynamic actuator replacing the passive wheelset guidance in the primary suspension, Figure 5(right). The vertical coil springs provides passive wheelset guidance, but the horizontal stiffness is not high enough to ensure running stability. With this actuator location, the actuator will be part of insuring vehicle safety. This setup is known as the yaw relaxation principle, where low yaw stiffness allows the wheelset to passively steer due to its conicity and the integrity of wheels and axle. One benefit with this principle is that the actuator forces are low, allowing use of just one actuator per axle, Figure 6. The actuator is foreseen to be a low force electro-dynamic actuator that is able to work at frequencies relevant for controlling the running behaviour.

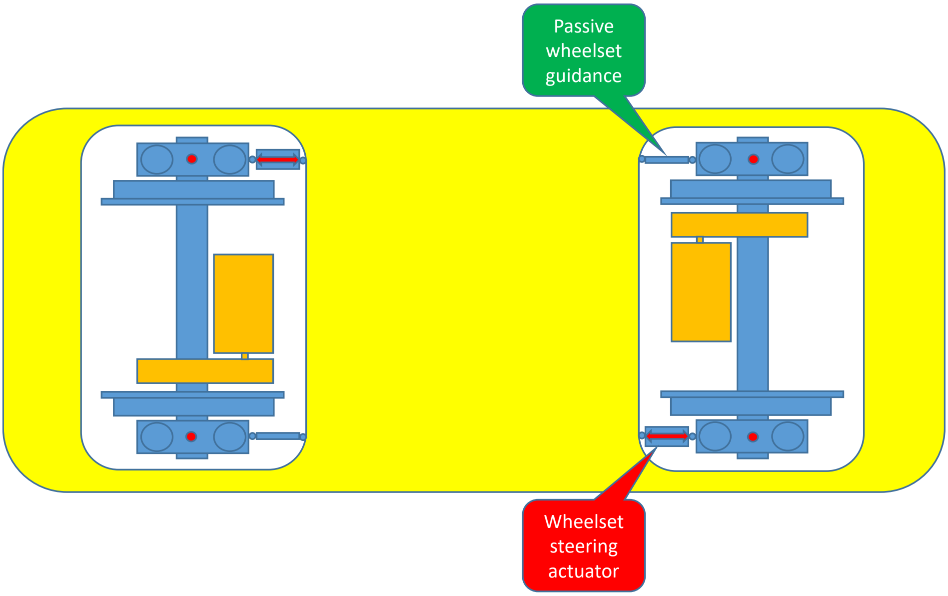

Figure 6: The running gear setup (top view)

3. RESULTS

3.1 FEASIBILITY OF THE VEHICLE

The objective of adding active suspension systems to the vehicle is to allow use of single axle running gears with one suspensions step. Such running gears are simple, low cost, low weight, and takes less space than conventional bogies. Hence, for this vehicle the active systems become an enabler for the entire vehicle concept.

The present calculations on weight and space show that it is possible to design a regional vehicle with zero emissions at the vehicle, level boarding for about 40 seated and 60 standing passengers and still meet the target on axle load.

3.2 ACTIVE SUSPENSION FOR RIDE COMFORT

The comfort evaluation for the vehicle in the Shift2Rail project Run2Rail shows that active vertical suspension significantly improves ride comfort making it possible to introduce a vehicle with single axle running gears and only one suspension step instead of conventional bogies. These simulations were made for a metro vehicle with similar properties as the now foreseen regional vehicle in FutuRe. However, the two vehicles differ in one way. The running gear in Run2Rail had an anti-roll-bar (ARB) built into the running gear frame that allowed the vertical suspension stiffness to be softer than in FutuRe, which does not have an ARB. A harder spring will transfer more vibrations from the wheelset to the body, which must be counteracted by the active suspension system. The enhanced properties for the active system mainly relate to the actuator itself that must be able to produce force at higher frequencies. The active system in Run2Rail relied on hydraulic actuators that gave ride comfort on the target, hence it is unlikely that they would be suitable for the FutuRe. Simulations on ride comfort for FutuRe have not yet been made yet, and the requirements for the actuator will be a result of the simulations.

3.3 WHEELSET STEERING FOR CURVING PERFORMANCE

A vehicle with such a long distance between the wheelset as foreseen here will have a challenge with the curving performance as the wheelset has to turn significantly to avoid the wheels running with flange contact through the curves that will cause both wear and energy losses. In a vehicle with passive wheelset guidance, the wheelset guidance will restrict turning the wheelset, when an active wheelset guidance can support the wheelset to take an approximately radial position in curves. In Run2Rail, the active system was set in parallel to passive wheelset guidance, while in FutuRe a replacement is foreseen, Figure . This setup gives two benefits, firstly the wear can be even lower in curves, and secondly the active force needed is significantly lower as the actuator is not counteracted by the passive wheelset guidance.

The effectiveness of active wheelset steering as wear number on the leading wheelset is shown in Figure 7. Wear numbers higher than about 200 J/m are known to cause significant wear on rails and wheels when low wear numbers risk to cause rolling contact fatigue (RCF). For best wheel life, there should be some wear to limit RCF crack initiation. Hence, optimal wheelset steering depends on several factors, where the curve radii distribution is the most important one. Regional lines often have curves with smaller curve radii than mainlines and the vehicle must be able to negotiate these without too much wear. The lowest wear numbers are shown for the active wheelset steering with the actuator in series with the passive wheelset guidance, but for most lines, the performance of the active wheelset guidance with the actuators in parallel is good enough. The active wheelset steering can reduce the wear for all radii, but can also be set to give some wear to avoid the risk of causing RCF.

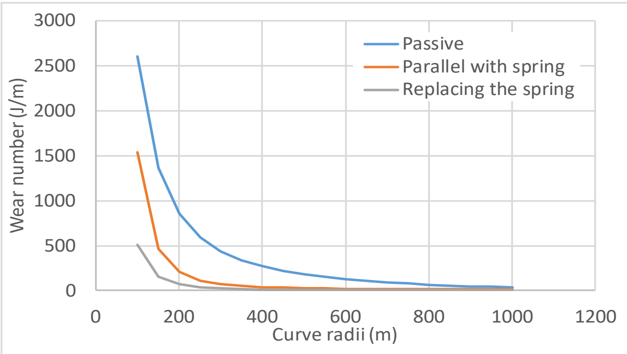

Figure 7: Wear number for leading outer wheel

4. KEY PERFORMANCE INDICATORS

The approach taken is to compare a set of Key Performance Indicators (KPI) relevant to resource efficiency for the proposed small regional vehicle to what the market can offer today. The KPIs used here are the four (4) used in FuTuRe. It would be unfair to exclude the larger capacity that today's trains offer. It is therefore assumed that 16 services a day in each direction are needed (one service departing every hour between 6 AM and 9 PM) and that the smaller vehicle must run in multiple operation in two services in the morning peak and two in the afternoon peak. Vehicle properties are shown in Table 2. As an example, the Swedish use case Gårdsjö – Håkantorp, a 121 km non-electrified regional line, is taken. Intermediate stops, gradients and speed profile are considered giving a simulated journey time of about 1 hour and 55 minutes, stopping times included.

Table 2: Vehicle properties

Property	Today's [1]	FutuRe
Number of trains	5 + 1 spare	5 + 2 +1 spare
Number of seats	70	40
Vehicle length	27 m	16 m
Tare weight	58 t	24 t
Weight loaded	72 t	32 t
Maximum speed	120 km/h	120 km/h
Power at wheel	600 kW	390 kW
Starting effort	70 kN	24 kN
Driving	Driver	Remote

4.1 ENERGY CONSUMPTION

The energy consumption is simulated for four (4) cases with details as in Table 3. The benefit of running the smaller vehicles in off peak becomes evident. The running gear is an enabler for the small size and low weight of the vehicles, but are other factors as the high power to weight ratio for the smaller vehicle that allows pure dynamic braking optimizing the energy feedback to the battery. Furthermore, the FutuRe vehicle is designed for remote (automatic) driving, which optimizes the driving compared to what a driver can do, but this difference is not accounted for in the simulations.

Table 3: Simulated energy consumption

Requirement	Today's		FutuRe	
Service	Off peak	Peak	Off peak	Peak
Passenger	20	60	20	2 x 30
Number of runs	28	4	28	4
Energy consumption (kWh/km)	2,59	2,68	1,21	2,26

4.2 NOISE EMISSIONS

The wheel-and-rail contact is the main source of external noise for a moving regional train. As the number of wheelsets is 2 on the FutuRe vehicle and 4 on today's vehicle, the sound energy is expected to be halved for the FutuRe vehicle which means a reduction by 3 dB. When the FutuRe vehicle runs in multiple there will be no difference.

4.3 MAINTENANCE

Very simplified, maintenance costs for rail vehicles (and the infrastructure) are derived from the number of wheelsets times their run kilometres, provided that their axle load is about the same. Today's vehicles produce 32 run * 121 km * 4 wheelsets = 15488 wheelset km a day, while the Future vehicle produces 36 * 121 * 2 = 8712 wheelset km.

4.4 PERSONNEL

The fourth KPI is related to the personnel needed to operate vehicle, but there is no influence by the running gear design on this KPI.

5. CONCLUSION

Single axle running gears are an enabler for the small size vehicle concept. In contrast, conventional bogies occupy a large portion of the underfloor area, making level boarding impossible or significantly limiting the low-floor section. Single axle running gears have two well-known deficiencies, poor curving performance and poor ride comfort. Both these deficiencies can be mitigated with low force active suspensions, which also supports removal of the on-board compressed air system. The single axle running gears positively influence three out of four KPIs used in FutuRe. The most important influence is on energy consumption, where usage of the small size vehicle instead of today's available vehicles with bogies leads to significant energy savings.

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REFERENCES

EU-Rail-FP6, Deliverable D5.1 State of the art report for regional lines rolling stock, https://www.ct5webapi.eu/api/documents/getfile?id=e2be4c49-007f-4704-87e4-86ab17452665

Shift2Rail – RUN2Rail, Innovative RUNning gear soluTiOns for new dependable, sustainable, intelligent and comfortable RAIL vehicles, http://www.run2rail.eu/

Goodall, R. M., Kortüm, W.: Active Controls in Ground Transportation Review of the State-of-the-Art and Future Potential, Veh. Syst. Dyn., vol. 12, no. 4–5, pp. 225–257, 1983.

Fu, B., Libero Giossi, R., Persson, R., Stichel, S., Bruni, S., Goodall, R.: Active Suspension in Railway Vehicles: A Literature Survey, Railway Engineering Science 28, 2020

Pacchioni, A., Goodall, R.M., Bruni, S.: Active suspension for a two-axle railway vehicle. Veh. Syst. Dyn. 48(sup1):105–120, 2010

Qazizadeh, A., Persson, R., Stichel, S.: On-track tests of active vertical suspension on a passenger train. Veh. Syst. Dyn 53(6):798–811, 2015

CEN; EN12299: Railway applications ride comfort for passengers measurement and evaluation, Brussels, 2009

Sugahara, Y., Kojima, T., Akami, Y., Igarashi, Y.: Development of a vertical semi-active suspension system using variable hydraulic dampers. In: Proceedings of the 15th international conference on railway engineering design and operation, 2016

Schneider, R.: Wankkompensation und aktive Radsatzsteuerung Flexx Tronic von Bombardier, Eisenbahn-Revue 4, 2020