

Possible reduction of energy consumption with single axle running gears in a metro train

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Running gears form a significant part of the weight of a railway vehicle, and if the weight of these could be reduced, this would affect the vehicle's energy consumption, especially for services with many stops. In the project RUN2Rail, a part of the EU-funded initiative Shift2Rail, a single axle running gear was proposed for metro vehicles. Active suspensions were suggested to overcome deficiencies in terms of ride comfort and wheelset steering, which are well known for such vehicles. The concept has been further developed in the project NextGear, also part of Shift2Rail, where the material of the running gear frame has been changed from steel to composite to further reduce the weight and the wheelset guidance updated to decrease the running resistance in curves. Prototypes of frame and wheelset steering actuator will be built and tested in the laboratory to validate the performance.

The present study is comparing a reference vehicle from Metro Madrid with the proposed vehicle in terms of energy consumption for simulated service on Metro Madrid Line 10 with curvature, gradients, stops and speed profiles considered. Only parameters with relation to the weight, curving performance and auxiliary energy consumption for the active system are assumed different for the vehicles. The vehicles are further assumed to use regenerative braking, hence the energy needed to accelerate the vehicle will be regenerated when braking, but there will be transformation losses with relation to the weight. The simulation results show that the very innovative NextGear vehicles will reduce energy consumption by 8% compared to the reference vehicles. The lower weight and the decreased running resistance in curves contribute about as much to the savings.

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1. Introduction

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. By adding active suspensions, the performance can be improved and brought up to level with conventional bogie vehicles. Active suspension with solutions as active tilting, hold-off-devices and active secondary suspensions have been employed on top of the line rail products [1], [2]. In the project RUN2Rail [3], a part of the EU-funded initiative Shift2Rail, active wheelset steering was proposed for a single axle running gear [4], [5]. The concept has been further developed in the project NextGear, also part of Shift2Rail, where the material of the running gear frame has been changed from steel to composite to further reduce the weight and the wheelset guidance updated to decrease the running resistance in curves.

The present study is comparing a reference vehicle from Metro Madrid with two proposed vehicles in terms of energy consumption for simulated service on Metro Madrid Line 10 with curvature, gradients, stops and speed profiles considered. The hypothesis is that the reduced weight and the active wheelset guidance will reduce the energy consumption in a metro application.

2. The vehicles

Metro Madrid is member of both the RUN2Rail and the NextGear projects, and it is therefore natural to take their vehicle as reference for the present study. Key data for the reference vehicle, MM S8000 [6], and the two proposed innovative 2-axle vehicles with single axle running gears (SARG) are shown in Table 1. The reference vehicle is 55 m long and challenging vehicles are given data as they would have for the same length. Parameters without relation to vehicle weight and curving resistance is assumed to be the same for all three vehicles, this group includes system efficiency, b and c-term for running resistance, acceleration and retardation. Parameters with relation to weight are assumed to vary linearly to weight, this group includes rotating masses, the a-term for running resistance, the maximum power and the tractive/braking effort. The passenger load is assumed as 500 kg/train meter. All dynamic braking is assumed for all vehicles and the auxiliary power is taken as 1 kW/train meter + the power for any active suspensions.

Table 1: Key data for the vehicles

Property	Unit	MM S8000	RUN2Rail	NextGear
Length	m	55	55	55
Tare weight	kg	104200	82500	80500
Addition due to rotating masses	kg	5210	4125	4025
Passenger load	kg	27500	27500	27500
Running resistance, term a	N	521	413	403
Running resistance, term b	N/(km/h)	10	10	10
Running resistance, term c ^{a)}	N/(km/h) ²	0.3	0.3	0.3
Maximum tractive power	kW	2280	1901	1866
Auxiliary power	kW	55	62	62
Starting tractive /braking effort	kN	137	114	112
Maximum acceleration	m/s ²	1	1	1
Maximum retardation	m/s ²	1	1	1
Maximum speed	m/s	33.3	33.3	33.3
Breaking speed ^{b)}	m/s	16.7	16.7	16.7

a) At open air, b) The speed where the tractive /braking effort begin to reduce due to available tractive power

The reduction in tare weight is directly derived from the design of the running gear. The innovative running gear has the axle boxes on the inside of the wheels, which makes the wheel axle shorter and the frame more compact. One suspension step is eliminated, and the remaining suspension step can be a simple coil spring design. The anti-roll function is integrated into the frame instead of being a separate part, Figure 1. The shape of the running gear composite frame designed within NextGear is shown in Figure 2. A prototype of the frame will be built and tested in the laboratory to validate the performance. The additional weight for any active system is included in the estimated weights.

The reduced weight of the running gear itself leads to that less axles can carry the payload per meter train and yet complying with the maximum allowed axle load of 15 tons. The weight of propulsion equipment and other components will be reduced as spinoffs of the reduced running gear weight and is estimated to 5500 kg per vehicle.

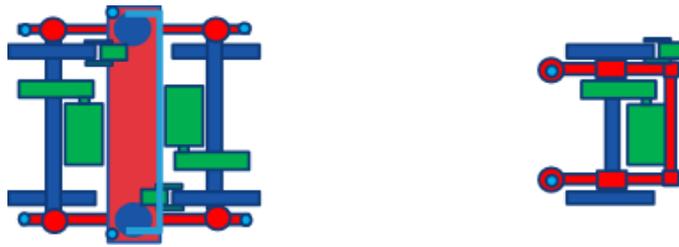


Figure 1: Conventional bogie design (left), the innovative running gear (right)

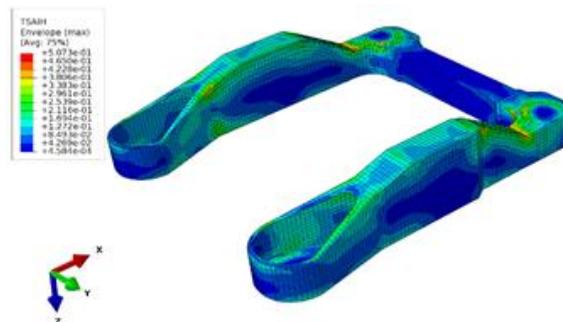


Figure 2: Strength calculation of the composite frame designed in NextGear

3. The active wheelset guidance

A vehicle with a passive suspension and as long wheelbase suggested for the vehicle with single axle running gears will have worse curving performance than the reference vehicle. On a metro line as the Madrid line 10 this would not only lead to unacceptable wear on wheels and rail, but also to unnecessary running resistance in curves. Active wheelset steering will improve the curving performance for the suggested vehicle to become better than the reference vehicle. For a curve with 300 m radius, which is typical on the line, the curve resistance will drop from 2676 N for the reference vehicle to 330 N for the RUN2Rail vehicle and even lower for the NextGear vehicle.

The actuators for the wheelset guidance are located directly between the axlebox and the carbody, Figure 3. The actuator has the passive wheelset guidance integrated into the same unit and is setup to work in parallel with the active system. The passive wheelset guidance ensures safety and the active system improves the curving performance. The drawback with this setup is that the active system must balance the forces from the passive guidance to create the needed yaw angle between axle and carbody [7]. In NextGear, the passive characteristic has been modified from linear to nonlinear to reduce the active force needed to achieve a radial wheelset position relative the track. A prototype of the wheelset steering actuator will be built and tested in the laboratory to validate the performance.

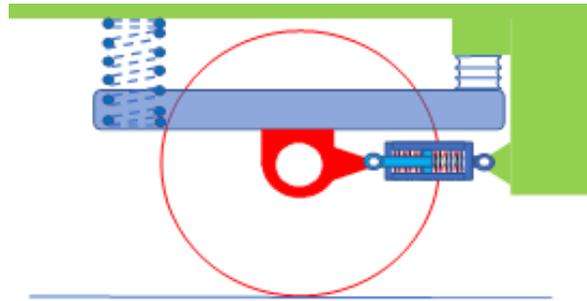


Figure 3: Side view of the single axle running gear with its wheelset steering actuator located between axlebox and carbody

4. The track network

The class 8000 vehicle is used on several lines of the Metro Madrid network. Line 10 is selected as reference as this line has sections with tight curves and other sections with relatively high speed making it suitable as a reference track, see Figure 4. The line goes from Hospital Infanta Sofía via Tres Olivos to Puerta del Sur. The low speed section located at 21.000 m contains as small curve radius as 100 m. Beside the speed profile and curvature, gradients and stops are considered.

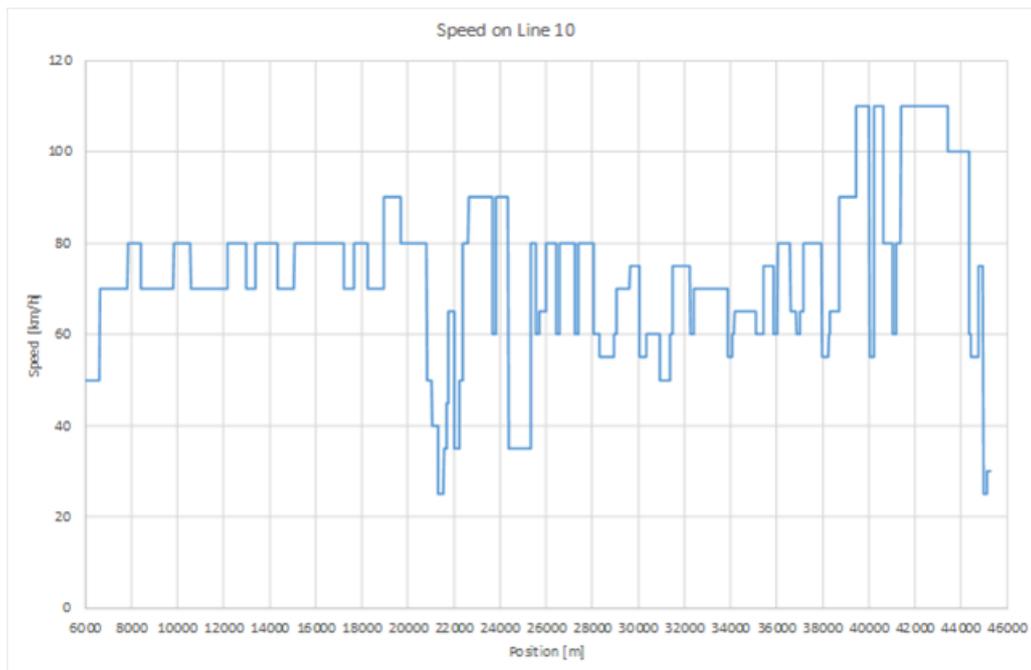


Figure 4: Line speed profile on Metro Madrid Line 10

5. Energy consumption

5.1 Calculation setup

The energy consumption is simulated for three vehicle types. The Metro Madrid class 8000 is the existing vehicle type on Line 10 and is therefore taken as reference for the study. The vehicle proposed in RUN2Rail and the further improved vehicle in NextGear are the challenging vehicles. The energy consumption for simulated service on Metro Madrid Line 10 with curvature, gradients, stops and speed profiles considered. Only parameters with relation to the weight, curving performance and auxiliary energy consumption for the active system are assumed different for the vehicles. The

vehicles are further assumed to use regenerative braking only, hence the energy needed to accelerate the vehicle will be regenerated when braking, but there will be transformation losses with relation to the weight. The calculations are made in two steps, first the vehicles are simulated on straight track with gradients and stops considered, which are performed with an in-house software STEC (Simulation of Train Energy Consumption) [8]. Most of Line 10 run in tunnels, where the aerodynamic drag is larger than in open air, this influence is considered by a standard add on derived by the Shift2Rail project FINE1 [9]. In the second step the curve resistance is added to the energy consumption.

5.2 Straight track

The simulation starts from Hospital Infanta Sofía via Tres Olivos to Puerta del Sur including all intermediate stops. The running resistance take account the increased drag in tunnels by an 80% addition on the running resistance c-term [10]. The auxiliary power consumption is considered as 1kw/train meter. On top of this 750 W constant power for the active suspensions per running gear is considered. It is here assumed that the running gear is equipped with active wheelset steering and active dynamic suspension in both vertical and lateral direction. The simulated gross power and reclaimed power is shown in Figure 5 and is summarized in Table 2. The reduction of about 5% in energy consumption is purely due to the weight difference as all other parameters are kept unchanged.

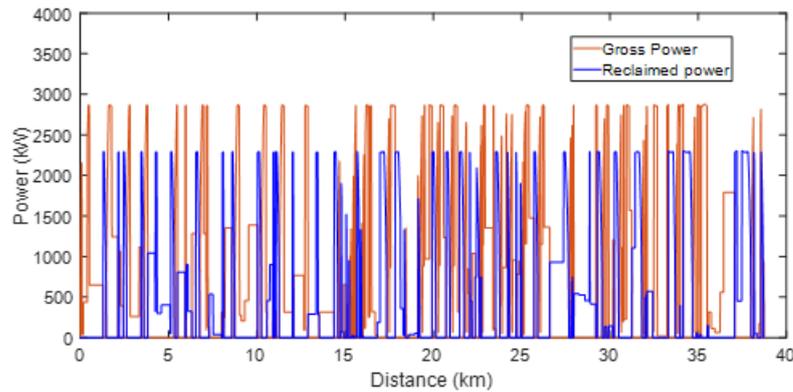


Figure 5: Gross power and reclaimed power as function of distance

Table 2: Energy consumption for one run at straight track

	Unit	Vehicle		
		MM S8000	Run2Rail	NextGear
Gross energy	kWh	520.9	454.8	448.4
Reclaimed energy	kWh	-334.5	-277.0	-271.8
Net energy	kWh	186.4	177.8	176.6
Reduction	%	-	4.6	5.3

5.3 Curve contribution

The additional resistance in curves and curve transitions is very dependent of wheelset guidance. Simulations are made with a multi body simulation tool (SIMPACK) where the vehicle with its masses, springs, dampers etc. are modelled. These simulations are made for a set of curves with constant radii aiming to find a regression between curve radius and curve resistance. The result is summarized in Figure 6. Different track segments are connected by clothoid transitions, where the curvature change linearly. Hence, also the curving resistance in transitions can be considered by the simulated results.

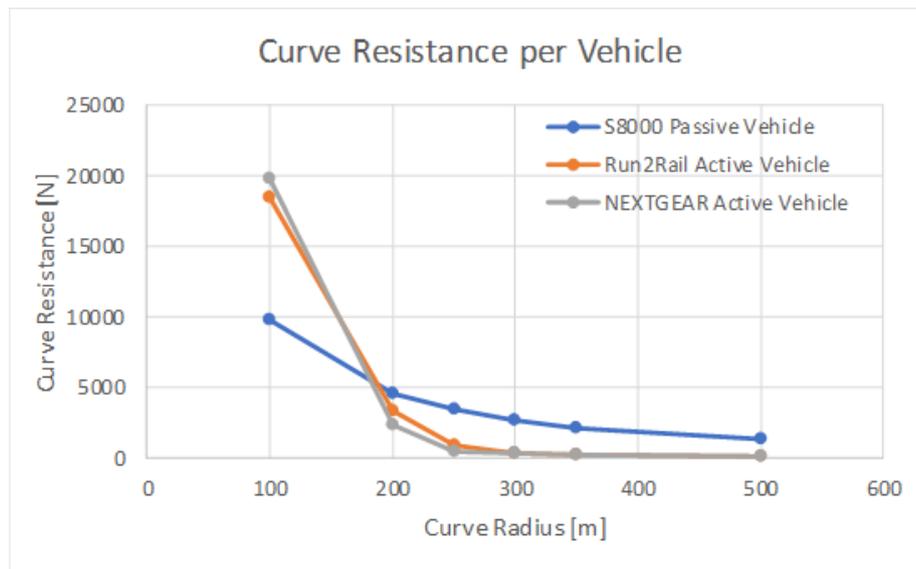


Figure 6: Curving resistance as function of curve radius for the three vehicles

The results for the two vehicles with active wheelset guidance are very good as long as the radii is not very small. At the smallest radius, the active wheelset guidance cannot compensate for the longer wheelbase compared to the reference vehicle due to the assumed actuation force limitation at 30 kN. However, as the number of small radii curves is low and the length of them limited the benefit with the challenging vehicles becomes a reduction with more than 80%, see **Error! Reference source not found.**

Table 3: Additional energy consumption in curves for one run

	Unit	Vehicle		
		MM S8000	Run2Rail	NextGear
Circular curves	kWh	6.5	1.3	1.1
Curve transitions	kWh	1.3	0.2	0.2
Total addition	kWh	7.8	1.5	1.3
Reduction	%	-	80.8	83.3

5.4 Total energy consumption

The total energy consumption is calculated as the sum of the energy consumption on straight track and the additional energy consumed in curves and curve transitions, see Table 4. The total energy consumed for one run on Metro Madrid Line 10 drops from 194.2 kWh for the reference vehicle to 179.3 kWh for the Run2Rail vehicle and even slightly lower for the NextGear vehicle.

Table 4: Total energy consumption for one run

	Unit	Vehicle		
		MM S8000	Run2Rail	NextGear
Straight track	kWh	186.4	177.8	176.6
Curves	kWh	7.8	1.5	1.3
Total	kWh	194.2	179.3	177.9
Reduction	%	-	7.7	8.4

6. Conclusion

The hypothesis is that the reduced weight and the active wheelset guidance will reduce the energy consumption in a metro application has been validated. Compared with a reference vehicle from Metro Madrid the simulated energy consumption on Metro Madrid Line 10 with curvature, gradients, stops and speed profiles considered the challenging vehicles reduce energy consumption by 8%. The lower weight and the decreased running resistance in curves contribute about as much to the savings.

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