# Control of Railway Wheelsets – A Semi-Active Approach

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**Abstract.** This paper presents a detailed study of semi-active approach for railway wheelsets. A number of control strategies for active primary suspensions for both solid axle wheelset and independently rotating wheelsets are examined in detail and the key requirements of energy flows on both curved and straight tracks are investigated. A semi-active control scheme is then proposed for the independently rotating wheels and a comprehensive performance evaluation is provided to demonstrate that the proposed semi active control system can be used to continuously and reliably provide the necessary steering control without the need for the energy injection of full active control.

**Keywords:** Railway wheelset control, Semi-active control, Solid-axle wheelset, Independently rotating wheelset.

## 1 Introduction

Active control for railway wheelsets can provide effective solutions to reduce substantially the contact forces and associated problems of wear/RCF and other track damages caused by passive primary suspensions [1]. Active control can be used to stabilise the inherent hunting of solid axle wheelset without interfering its natural curving ability or to supplement the passive suspensions with additional steering action on curves [2]. It can also provide the necessary guidance control that is missing in independently-rotating wheels [3].

However, full active control necessitates the use of actuators that are capable of both injecting into and dissipate energy from the system and such actuators are not only expensive but also tend to be bulky in size – this can lead to considerable increase in the overall costs of railway vehicles and also difficulties in installations in space tight bogie frames. In addition, active wheelset control is safety critical and the use of hardware redundancies (e.g. duplication of actuators) would exacerbate the problems and potentially hinder or even prevent practical adoption of such technologies for commercial applications despite its clear advantages.

There have been a few studies of semi-active approaches for solid axle wheelset, looking into the possible use of variable/controllable passive devices to replace the more costly actuators. Variable longitudinal stiffness in the primary suspensions has been proposed to improve the hunting instability of railway carriages [4]. It would clearly be beneficial to be able to increase the stiffness for high speed operations and reduce it when a vehicle negotiate tight curves at low speeds, but mechanisms to achieve this could be problematic in practice. The use of variable dampers either in the primary suspensions to supplement the passive means [5] or in the secondary suspensions to replace the yaw dampers of fixed coefficient [6] can help to improve the vehicle performance, but they do not solve the fundamental trade-off between the stability and curving of the solid axle wheelsets. So far, no studies on the semi-active control of independently rotating wheelsets are found.

The control of railway wheelset is concerned with the issues of stability and/or track following – both issues are safety critical and therefore the research challenge for any semi-active control approach is to provide the necessary control effort at all times within the obvious constraint of energy dissipation only (i.e. no energy injection into the system). This is significantly more demanding than the semi-active control for secondary suspensions where the switching between active and passive modes is inherent and accepted.

In this paper, detailed studies of control design for active primary suspensions with solid axle wheelset and independently rotating wheelsets are presented to examine power flows on different track conditions. A control scheme for the active steering of independently rotating wheelsets (IRW) that can be implemented with semi-active means (via the use of variable/controller dampers) is proposed. The semi-active control scheme, where the control is achieved with the use of magnetorheological (MR) dampers, is then applied to a two-axle vehicle with IRWs. Computer simulation results demonstrate that the proposed semi active control system can be used to continuously and reliably provide the necessary steering control without the need for any energy injection of full active control.

## 2 Semi-Active Devices

There are broadly three categories of variable devices that can be used for semi-active controls – variable stiffness springs, variable dampers and variable inerters. The variable springs involve some form of moveable mechanisms or vary the load transfer ratio by moving the location of the point of attachment to control stiffnesses [7, 8]. The variable dampers control the damping forces by either adjusting flow rate of the fluid in the device by controlling orifice positions [9] or changing the characteristics of the fluid using magnetic/electro means [6]. The variable inerters produce the forces that are proportional to the acceleration between the two terminals of the device with a controllable-inertia flywheel such that the effective inertia is adjustable [10].

The variable stiffness or inerters are capable of storing and returning energy from/back to a system, but the use of moveable mechanisms tends to slow the control responses and also potentially raises the reliability issues that are critical for the control of railway wheelsets.

On the other hand, the variable dampers are by far the most commonly used for semi-active control applications – they are relatively straight forward to control with very fast responses, but they are not able to dissipate energy in the system so can only be used in applications where energy injection or storage is required.

# 3 Control Analysis

This study examines the known active wheelset control schemes and explores the potentials for implementation using variable dampers rather than full active controls. The use of variable stiffness or inerter is not considered in this study, not only because of the reasons mentioned above but also it would likely require different control design approaches. Also, the analysis is limited to active controls as a replacement of passive suspensions rather than supplementary to passive stabilization such that the full advantage of active control is obtained.

The solid-axle wheelset can provide the self-centering/steering on a track, and perfect curving is maintained if this natural curving is not interfered by the stabilization that is necessary to manage the unstable kinematic mode [11]. The stability control (whether classical control strategies or model based approaches) require feedback signals that are out-phase with the control effort (e.g. yaw control) such as the yaw angle or lateral velocity of the wheelset [12-15]. Consequently, the control will require both injecting and dissipating power at different times, which makes it impossible to use the semi-active devices such as variable dampers. Figures 1 and 2 show the power requirement of an actively stabilized solid-axle wheelset on straight and curved tracks respectively. It is clear that the control will need to provide energy (negative power) at most times and consume energy (positive power) at other times.

On the other hand, independently rotating wheelsets require both stabilization and guidance control as the natural curving is not available because the two wheels on an axle are allowed to rotate freely. However, provision of the stabilization and guidance control for independently rotating wheelsets is much more straight forward than that for the solid-axle counterparts. Not only the required control effort is much lower, but also it is possible to only use the feedback signals that are in phase with the control effort [3]. Figures 3 and 4 show that the power requirement of an actively controlled independently rotating wheelset can be made to consume power only – paving the way for the implementation with semi-active means.

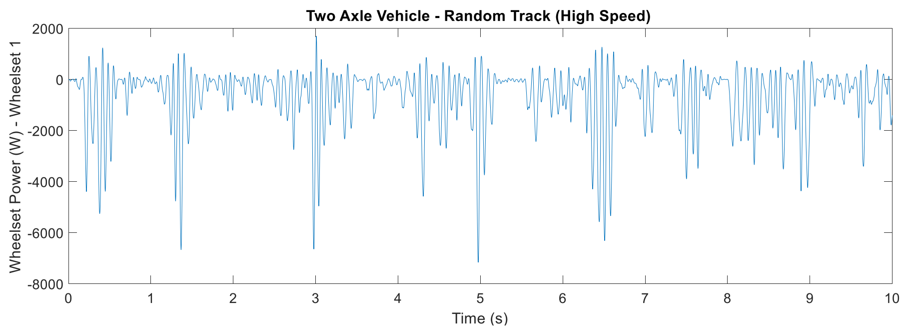


Figure 1 Power of active control on straight track with irregularities – solid axle

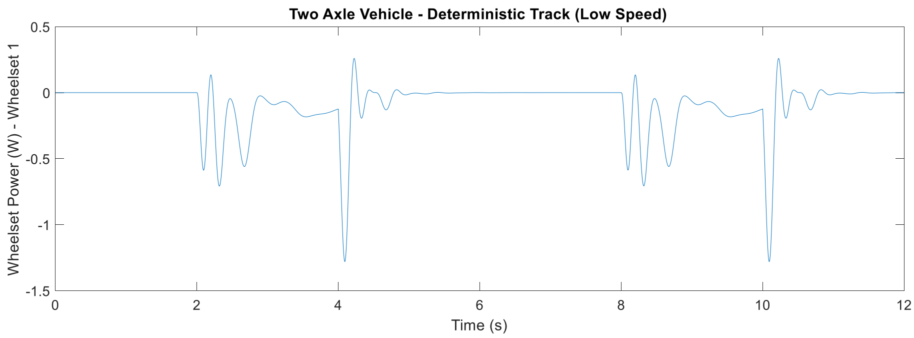


Figure 2 Power of active control on curved track – solid axle

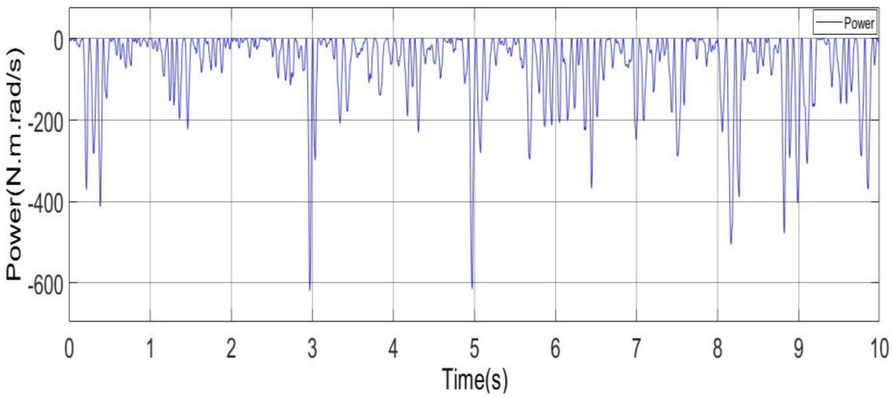


Figure 3 Power of active control on straight track with irregularities – IRW

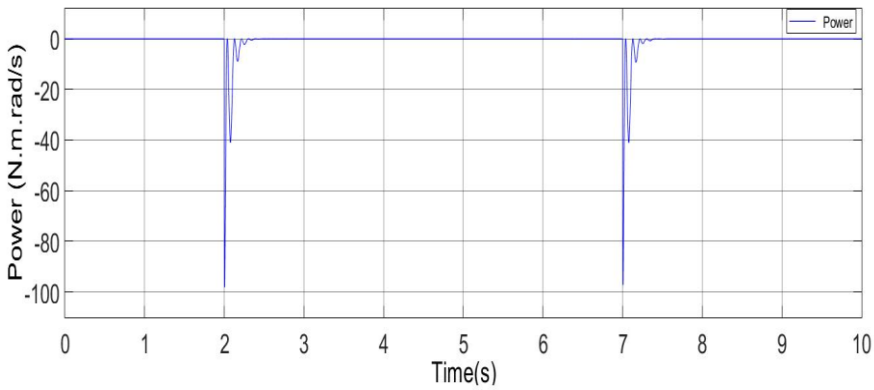


Figure 4 Power of active control on curved track – IRW

## 4 Semi-Active Control

Figure 5 shows the proposed semi-active control scheme for a 2-axle vehicle with independently rotating wheelsets. This is very similar to a full active control system, but the actuators are now replaced with variable dampers – in this case, magnetorheological dampers are used for their ease of control and fast response.

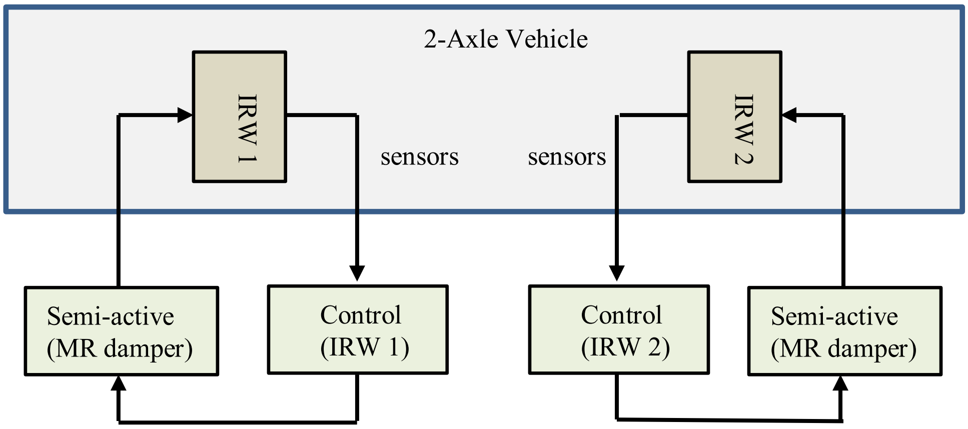


Figure 5. Semi-active control scheme of a 2-axle vehicle with IRWs

Figures 6-8 compare the control effort, the velocity and power of the control device of the proposed semi-active control approach with those of a full active control on a high speed straight track. It can be seen that the semi-active performs as well as the full active. No power injection is needed and no extra benefits may be expected from the full active control

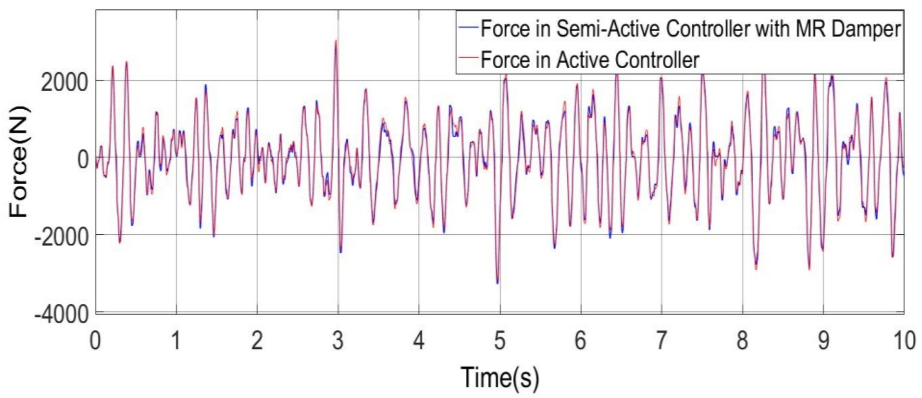


Figure 6. Control effort on a straight track – Full active vs Semi-active

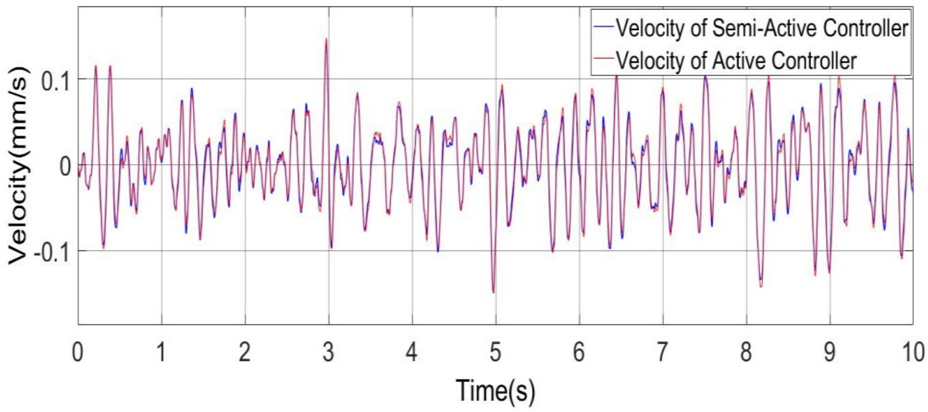


Figure 7. Velocity of MR damper on a straight track – Full active vs Semi-active

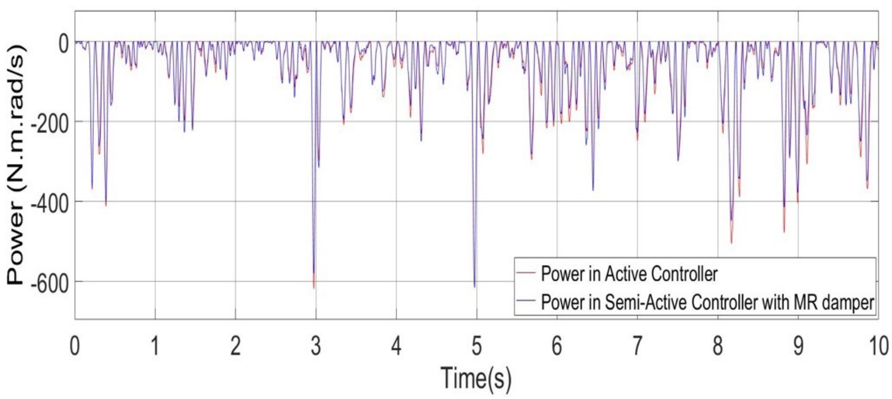


Figure 8. Power on a straight track – Full active vs Semi-active

The semi-active control is also capable of providing the necessary guidance on curved track. Figures 9-11 compare the control effort, the velocity and power of the control device of the proposed semi-active control approach with those of a full active control on a curved track. Again, there are not much differences between the two as the control system in either case only dissipate the energy from the wheelset and there is no requirement to provide any additional energy.

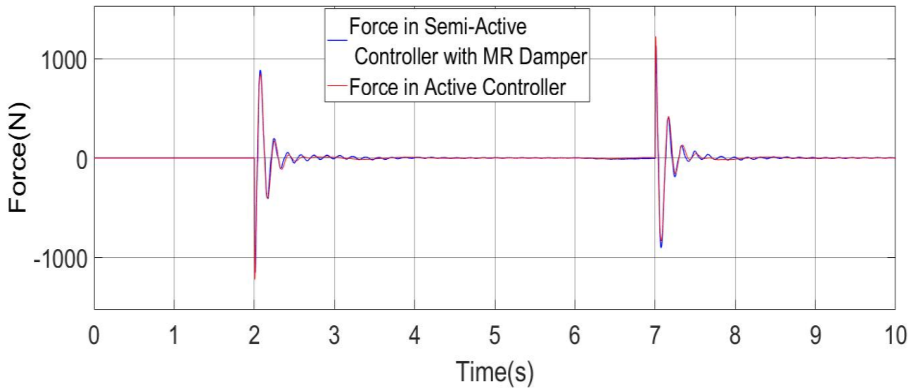


Figure 9. Control effort on a curved track – Full active vs Semi-active

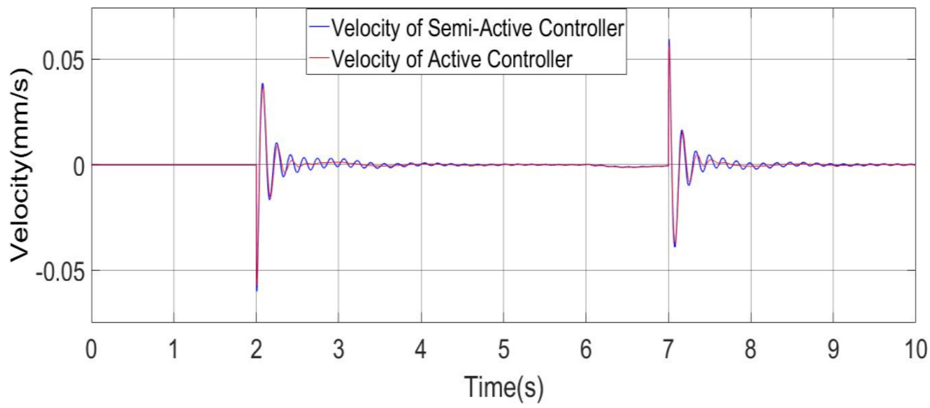


Figure 10. Velocity of MR damper on a curved track – Full active vs Semi-active

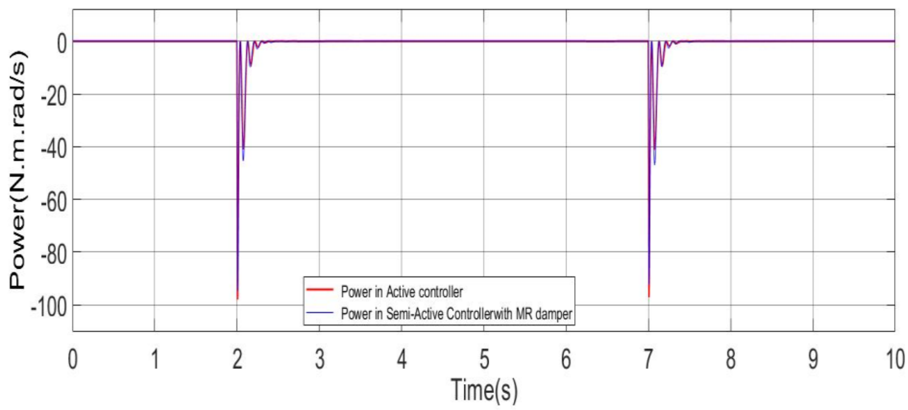


Figure 11. Power on a curved track – Full active vs Semi-active

## 5 Conclusions

This paper has presented the development of a semi-active control scheme for the independently rotating wheelsets in railway vehicles. Detailed analysis of the control requirements and power flows are provided. Computer simulation has demonstrated that the proposed semi-active control can be used to deliver the stability and guidance control for independently-rotating wheelsets that matches the performance of a full active control, providing a much more cost effective way for active wheelset control In the future.

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