EFFECTS OF INERTANCE IN RAILWAY VEHICLES WITH ACTIVE CONTROL

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Summary This paper presents research achievements associated to the effects of introducing novel passive suspensions to a railway vehicle secondary vertical and primary longitudinal suspensions when active solutions are applied for ride quality and stability problems, respectively. A reduction in the active force is obtained for the vertical model, and a very significant improvement of the lateral stability is attained when an active torque is applied to a vehicle with a longitudinal novel suspension incorporating inerters.

ACTIVE SOLUTIONS IN RAILWAY VEHICLES

Mechatronics –including active suspensions– has been introduced for the multiple railway vehicle problems over the last few decades. Several configurations of active solutions have been studied for solving the main problems arising in a railway vehicle, in conjunction with the passive suspensions of a typical vehicle. Important trade-offs associated with different control objectives according to the track features i.e. deterministic and stochastic conditions, physical constraints and power requirements in the case of active solutions normally dominate the design procedure. Bruni et al. in [1] present the state of the art for control and monitoring of railway vehicles in 2007. Although research in the field has continued since then, this state of the art for active suspensions can be considered to be still up-to-date. This paper explores the effect of including inertance into the suspensions for two selected active solutions described below. *Inertance* is a term introduced with the development of the inerter [2], which has expanded the set of passive suspensions that can be synthesised using simple mechanical elements (i.e. springs and dampers). Novel passive suspensions that include inerters allow the implementation of mechanical structures including also relative acceleration effects, translated into a modification of the kinetic energy function of the system. Previous research has explored the effect of novel passive suspensions with different mechanical impedance in the railway vehicle (see [3] for example).

EFFECTS OF INERTANCE FOR VERTICAL RIDE QUALITY

Here, for vertical ride quality enhancement of the railway vehicle with two-stages suspension in [4], an ideal actuator in parallel to the conventional secondary suspension (airspring) is controlled by feedback of the vertical absolute velocity of the vehicle body ("skyhook damping") with high-pass filtering [1, 5]. For this research, a novel passive suspension consisting of a series inerter-spring-damper is also inserted in parallel. Parameters of the active and novel passive suspension were tuned using genetic algorithms for solving the multiobjective optimisation problem of minimising at the same time: the vertical vibrations of the vehicle body (J1), the maximum secondary suspension deflection to deterministic and stochastic track profiles (J2), and the maximum active force (F); physical constraints were imposed to the parameters values only[1]. Figure 1 shows the optimisation trade-offs for the quarter vehicle with active suspension and with/out the novel passive suspension in parallel. It can be noticed how the use of the novel mechanical structure enhances the ride quality of the vehicle while maintaining the same levels of suspension deflection, allowing the reduction of the size of the actuator for achieving the same ride quality compared with the active suspension only.

EFFECTS OF INERTANCE FOR LATERAL STABILITY

For assessing the problem of lateral stability, active torque control for the wheelsets utilising an absolute yaw stiffness feedback ("skyhook stiffness") strategy [6] is applied. The strategy considers a control gain K_u with high-pass filtering of the measurement at 1 Hz to provide stability without affecting curving. The plan-view model of the vehicle used here is the one presented in [3]. The model includes the lateral and yaw dynamics of the two wheelsets and the bogie, and also the lateral dynamic of the half vehicle body. The original (passive) vehicle has a longitudinal spring (with stiffness K_{px}) guaranteeing the vehicle stability through yaw stiffness, although this significantly compromises curving performance. This is replaced by: a) a series spring-damper-inerter, and b) a series spring-damper in the study of different longitudinal suspensions. The parameters of the active solution and the longitudinal suspension were tuned for a design speed of $55 ms^{-1}$ using genetic algorithms for maximising the least damping ratio of the vehicle kinematics and minimising the longitudinal stiffness of the passive spring.. The latter requirement is due to the fact that longitudinal stiffness adds complexity and difficulties to the stabilisation of the bogie because of the high interaction

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[1] Inertance: 50-2500 kg, stiffness: 0.5-5 MN/m, damping: 10-50 kN/ms^{-1}, control gain: 10 N/ms^{-1}-0.16 MN/ms^{-1}, and cut-off frequency: 0.1-0.5 Hz.

between the two wheelsets and the relatively light bogie frame [6]. Physical constraints were imposed upon the parameters in the formulation of the optimisation problem[2].

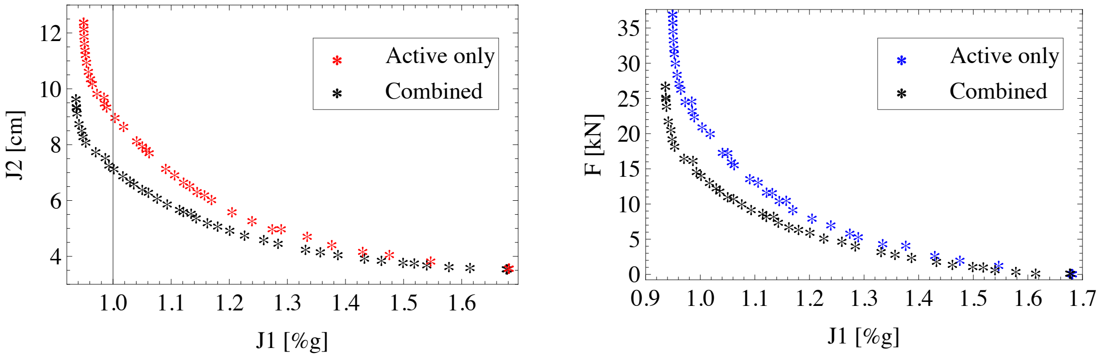

Figure 1: Trade-offs J1 vs J2 and J1 vs F for the active suspension only and for the combined suspension.

For a conventional vehicle running at the nominal speed, the least damping ratio is 0.32% (with K_{px} =37.66 MN/m), while for K_{px} set to zero the maximum least damping ratio is 12% when the vehicle is actively stabilised. Figure 2 shows the trade-off resulting between the least damping ratio and the longitudinal stiffness for: 1) the novel suspension in a) without active torque, 2) same as 1) but with active torque, 3) suspension in b) with active torque, and 4) a pure longitudinal spring with active torque. The figure depicts that an improvement in the stability is attained with the relaxation of the longitudinal stiffness (configurations 2 and 3) for high stiffness values, and that inertance in the configuration 2 allows a much better improvement over configuration 3. The insertion of the inerter allows higher control gains than the other configurations. On the other hand, pure passive suspensions can only achieve stability with high longitudinal stiffness values that are detrimental to curving performance (high wheel and rail wear).

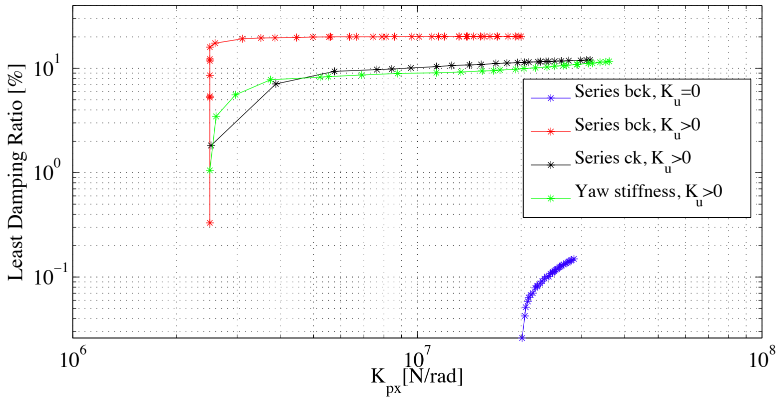

Figure 2: Trade-off between the longitudinal stiffness coefficient and the least damping ratio of the half-vehicle kinematics for the four cases mentioned above.

CONCLUSIONS

Modification of the system's kinetic energy caused by the insertion of an inerter in the vehicle's suspensions is beneficial for the application of active solutions. In the two scenarios studied here, the inerter enhances the vehicle performance allowing either an additional improvement of the main control objective or a reduction of the actuators' size and a simplification of the design trade-offs.

References

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[2] For combined suspensions: Control gain: 10-50 MN/m, inertance: 3000-100000 kg, stiffness: 2.5-40 MN/m, and damping: 5-500 kN/ms^{-1}. For the novel passive suspension only, the longitudinal stiffness range was constrained between 20 and 40 MN/m.