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RAILWAY VEHICLE VIBRATION DYNAMICS AND OPTIMIZED BOGIE DAMPING TO ENHANCE SAFETY AND COMFORT

Viktor Berbyuk*[a)] & Albin Johnsson**
Department of Applied Mechanics, Chalmers University of Technology,
SE-412 96, Gothenburg, Sweden
***Xdin AB, A Odhners Gata 41, SE-421 30, Västra Frölunda, Sweden*

Summary The paper presents results on analysis of vibration dynamics of a high speed train (HST) and multi-objective optimization of damping characteristics of bogie's primary and secondary suspensions to enhance safety and comfort. The results of optimization are presented via Pareto fronts and Pareto sets providing deep insight into the vehicle vibration dynamics. The obtained results make it possible to propose adaptive control strategies for switching suspensions' damping parameters to enhance safety and comfort and to increase the vehicle service speeds.

INTRODUCTION

Vibration dynamics and control of different subsystems of railway vehicles is an active area of research. Recent activities include improvement of train-set performance by novel design of the bogie suspensions, see, e.g., [1]. In particular the use of active or semi-active components such as electromechanical elements and magnetorheological dampers, have proven to improve the performance and make higher service speeds possible, see, e.g., [2]. By introducing active/semi-active suspensions it is also important to understand the limits of the conventional suspensions' solutions. Optimized passive suspensions can also improve the performance of trains significantly. The performance is measured by the objectives such as safety, ride comfort and level of wear of wheel and rails. These objectives are in general conflicting. The proposed paper presents results on analysis of vibration dynamics of a HST, multi-objective optimization of damping properties of bogie's primary and secondary suspensions, and on design of adaptive control strategies for switching suspensions' damping parameters allowing railway vehicle higher service speeds and enhanced safety and comfort.

MODELING OF RAILWAY VEHICLE VIBRATION DYNAMICS

The HST coupled with a dynamical track is considered. The entire model is established in the commercial software Gensys [3] and consists of three carbodies, six bogies, twelve wheelsets and twelve track segments on which the wheelsets are running. The motions of the carbodies, bogies, wheelsets and tracks are described by the governing equations of the vehicle and track dynamics. The bodies are connected with four coupling systems: the primary and secondary suspensions which connect the bogie frame with the wheelsets and the carbody with the bogie frame, respectively, the car-to-car couplers and the wheel-rail contacts. The suspension systems consist of conventional passive linear and nonlinear spring and damper functional components.

The motion of the railway vehicle is described by the equation

$$\dot{\mathbf{x}} = \mathbf{f}(t, \mathbf{x}, \mathbf{d}, \mathbf{p}, \mathbf{s}, \mathbf{u}, V), \qquad \mathbf{x}(0) = \mathbf{x}_0, \qquad t \in [t_0, t_f], \tag{1}$$

where **x** is the state vector, **d** is the vector of design parameters, **p** is the vector of given system's structural parameters which includes the stiffness, massinertia parameters and other structural parameters, **s** is the vector of given system's dynamics parameters including parameters such as coefficient of frictions, contact model parameters and geometrical parameters of track and wheel, **u** is the disturbances from the track irregularities, V is the forward speed of the train, and $\mathbf{x}_0, t_0, t_f$ are the initial state of the system, the initial and the final instants of time.

The main performance qualities that the bogie system dynamics do affect are safety, ride comfort, and the ability to decrease the rate of wear as well as crack initialization and propagation in rails and wheels. The safety of a train is defined by the contact forces on the wheels due to the wheel-rail interaction, which have potential to damage both rails and wheels and to cause derailment. Low lateral forces are associated with stable motions. The ratio between lateral and vertical forces in the wheel rail contact is used for determining risk of derailment. The ride comfort is measured using the acceleration of the carbody. The points of measure are located at floor level over the bogies and in the geometric center for each car. The accelerations are frequency-weighed to better represent the human perspective of comfort. The rate of wear of rails and wheels is measured using the wear number. The wear number represents energy dissipation in the contact surface and is described by the force and creep in the contact point.

[a)] Corresponding author. Email: viktor.berbyuk@chalmers.se

VIBRATION DYNAMICS ANALISYS AND DAMPING OPTIMIZATION

Problem A. Let we are given by the vector of the system's structural parameters $\mathbf{p}=\mathbf{p}_0$, the vector of the system's dynamics parameters $\mathbf{s}=\mathbf{s}_0$, the disturbances from the track irregularities $\mathbf{u}=\mathbf{u}_0$, the forward speed of the train $V=V_0$, and $\mathbf{x}_0, t_0, t_f$ - the initial state of the system, the initial and the final instants of time. It's required to determine the vehicle vibration dynamics, i.e. the state vector $\mathbf{x}^*(t)$ as the solution to the initial value problem (1) and the vector of design parameters $\mathbf{d}=\mathbf{d}^*$ which all together satisfy the following variational equation

$$\mathbf{F}[\mathbf{x}^*(t),\mathbf{d}^*]=\min_{\mathbf{d}\in\Omega}\mathbf{F}[\mathbf{x}(t),\mathbf{d}],\qquad \Omega=\{\mathbf{d}:\mathbf{d}_l\le\mathbf{d}\le\mathbf{d}_u\},\tag{2}$$

In the equation (2) **F**=[F_{S1} ,F_{C1}] is the vector of safety and ride comfort objectives respectively.

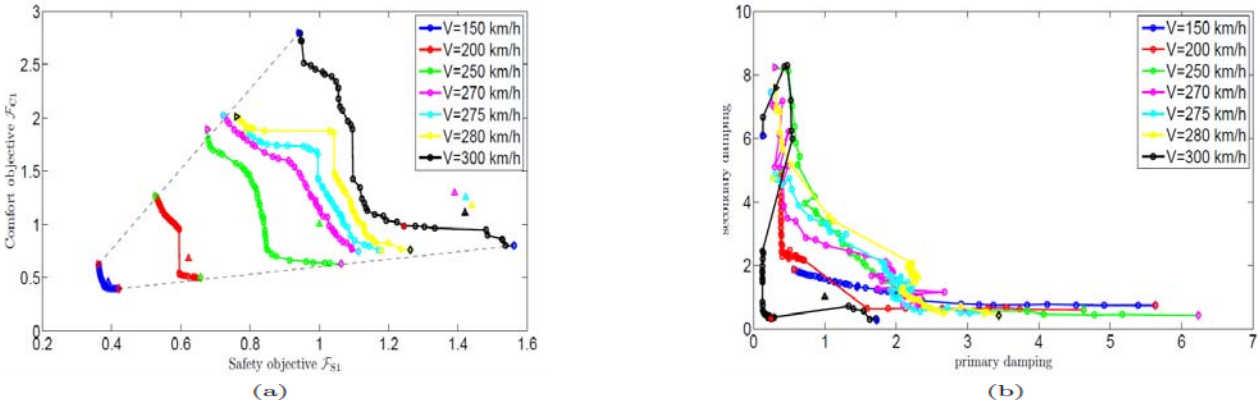

Fig. 1 Normalized Pareto fronts (a) and Pareto sets (b)

The algorithm of solution of the Problem A has been developed and implemented in Matlab using multi-objective evolutional optimization routine *gamultiobj*. The parameters to be optimized are the lateral and the longitudinal damping coefficients of bogie's primary and the secondary suspensions. The solution of the Problem A has been obtained for different set of input data. The results are presented via comfort-safety Pareto fronts and the respective Pareto sets of the design parameters. As an example, Fig. 2 presents Pareto fronts, Fig. (a), and the respective Pareto sets, Fig. (b) for different vehicle velocities *V*. The curves are normalized w.r.t. in–service vehicle configuration running at 250 km/h. The safety, F_{S1}, and comfort, F_{C1}, objectives captured the major part of the Pareto fronts. The total improvement is about 20% of the safety objective and 40% of the comfort objective compared to the in-service configuration for the vehicle running at 270 km/h. The set of optimized solutions provide deep insight into the railway vehicle vibration dynamics which can be utilized in decision regarding the design of bogie suspensions and structural control. By using the obtained Pareto fronts a few adaptive control strategies have been proposed to control switching the damping characteristics of bogie suspensions with respect to forward speed. The results showed that the proposed adaptive control strategies can increase the quality of performance of the vehicle even further compared to optimized passive trade-off solutions within the considered case.

CONCLUSIONS

The paper presents the results on analysis of vibration dynamics of a high speed train and multi-objective optimization of damping characteristics of bogie's primary and secondary suspensions to enhance safety and comfort. To study the HST vibration dynamics the multibody system model has been developed and implemented in software Gensys. By using the developed model and evolutionary algorithm the lateral damping parameters of primary and secondary suspensions have been optimized. The results of optimization are presented via Pareto fronts with respect to safety and comfort objectives and via Pareto sets with respect to lateral damping parameters of bogie's primary and secondary suspensions. By using the obtained results adaptive control strategies have been proposed for switching suspensions' damping parameters to enhance safety and comfort and to increase the railway vehicle service speeds.

References

[1] Zolotas A.C., Pearson J.T., Goodall R.: Modelling Requirements for the Design of Active Stability Control Strategies for a High Speed Bogie. *Multibody Syst. Dyn.***15**: 51-66, 2006.

[2] Wang D.H., Liao W.H. Semi-active suspension systems for railway vehicles using magnetorheological dampers. Part I: system integration and modelling, *Vehicle System Dynamics,* **47:**1305–1325, 2009.

[3] Persson I. GENSYS Reference Manual, (2011), Available at http://www.gensys.se.