The Use of Active Vertical Secondary Suspension to Improve Ride Comfort in a Rail Vehicle

KTH Engineering Sciences

Active vertical secondary suspension (AVS) in a rail vehicle enables significant ride comfort improvement as compared to a passive system. In addition to vertical dynamic control, the actuators can generate quasi-static roll control of the car body. This allows for higher speed in curves without negative effects on ride comfort.

INTRODUCTION

In rail operation today, the general trend is aiming towards increased vehicle speeds. However, higher speeds usually generate increased forces and accelerations on the vehicle which have a negative effect on ride comfort. The suspension of the vehicle has to be modified in order to compensate for amplified vibrations in the car body. The possibilities of improvement by means of conventional passive damping are reaching their limit. Active suspension technology is considered a viable alternative to passive solutions because it offers more options for improving a vehicle's dynamic performance.

The study of active vertical secondary suspension (AVS) is part of the Swedish research and development program Gröna Tåget (Green Train), which aims at developing a concept for the next generation of high-speed trains for Nordic conditions. The overall focus is to increase vehicle speed from today's 200 km/h to 250 km/h on existing conventional lines and up to around 300 km/h on new dedicated high-speed lines. With the AVS system, ride comfort can be improved, or at least maintained, at increased vehicle speeds or when track conditions are unfavorable.

> *"With the active vertical suspension system, ride comfort can be improved, or at least maintained, at increased vehicle speeds or when track conditions are unfavorable."*

SIMULATION MODEL

The vehicle model in SIMPACK was originally developed by Bombardier Transportation and models a one-car "Regina" vehicle with a flexible car body connected to two motor bogies through the secondary suspension (Fig. 1). The two conventional vertical dampers in each bogie are replaced by two vertical actuators (Fig. 2).

The idea is to reduce the car body vibrations by using the vertical car body accelerations as reference signals. The signals are processed in the controller to create the appropriate force demands on the actuators. The generated actuator forces then counteract and reduce the car body vibrations.

The control strategy is modeled in the MATLAB® tool Simulink® (Fig. 3). In addtion to passive systems, dynamic vertical control is applied to further reduce vibrations of the car body and hence improve ride comfort. Further, quasi-static roll control is applied to reduce the relative roll angle between the car body and bogies thus enabling higher speed in curves without negatively impacting ride comfort.

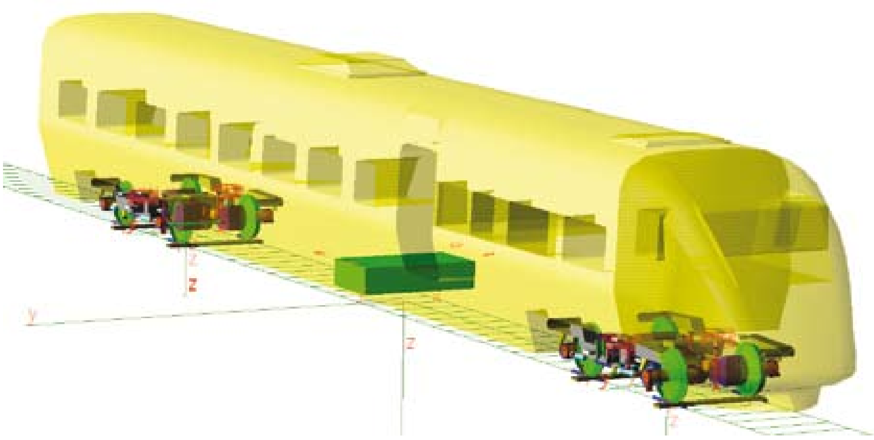

Fig. 1: The SIMPACK simulation model

The actuator used in this study is an electro-hydraulic actuator modeled with its actual characteristics in Simulink. It is able to generate a force response up to 30 kN for a relative speed of 50 mm/s.

CO-SIMULATION

By means of the co-simulation interface SIMAT, SIMPACK and Simulink are able to communicate and exchange data (Fig. 3).
The simulation is initiated in SIMPACK by starting a server to which MATLAB is connected. The simulation time and other integration parameters are given in MATLAB which acts as master. SIMPACK acts as slave and reacts to these parameters. As the simulation is started in MATLAB, the two programs are independently solving their part of the equation system during one sample time period. At the end of each period, data is exchanged between the two programs and the process continues until the end of the simulation time. Measurements have to

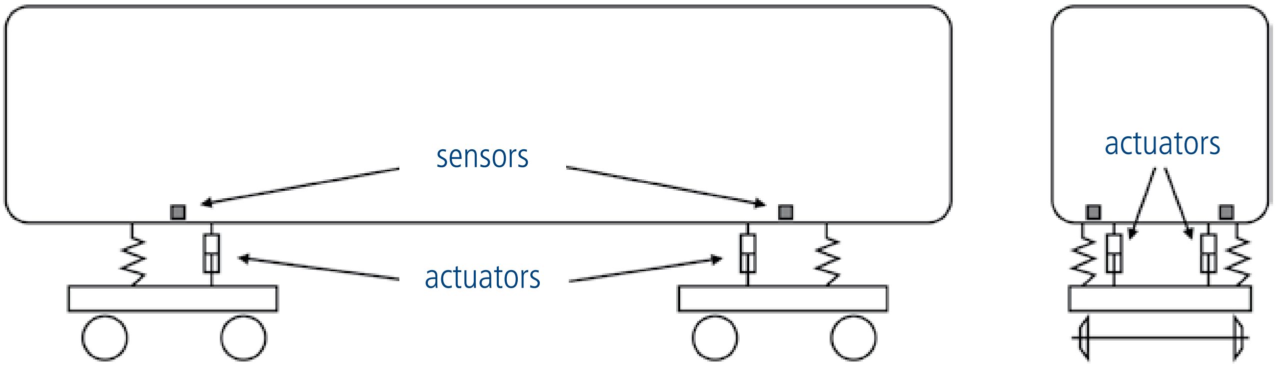

Fig. 2: Vertical actuators in the vehicle model

be performed after the termination of the simulation for post-processing of the simulation results.

DYNAMIC AND QUASI-STATIC CONTROL

Dynamic control reduces car body vibrations, particularly on straight and large-radius tracks at high speeds. In the present study, this is achieved by means of so-called sky-hook damping which is a straightforward and commonly used active control strategy in rail vehicles. The reference signals are filtered, integrated and multiplied by damping coefficients to create the appropriate force demands on the actuators.

The quasi-static roll control enables a reduction of the car body roll outwards in curves. Depending on the tuning of the system, it is even possible to achieve inwards tilting. This reduces the lateral acceleration felt by passengers, and higher speeds in curves can be achieved without the need to increase the track cant.

"…it is even possible to achieve inwards tilting. This reduces the lateral acceleration felt by passengers…"

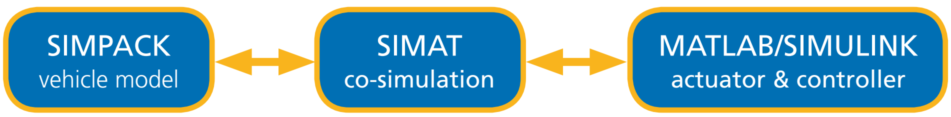

Fig. 3: The SIMAT interface enables co-simulation between SIMPACK and MATLAB

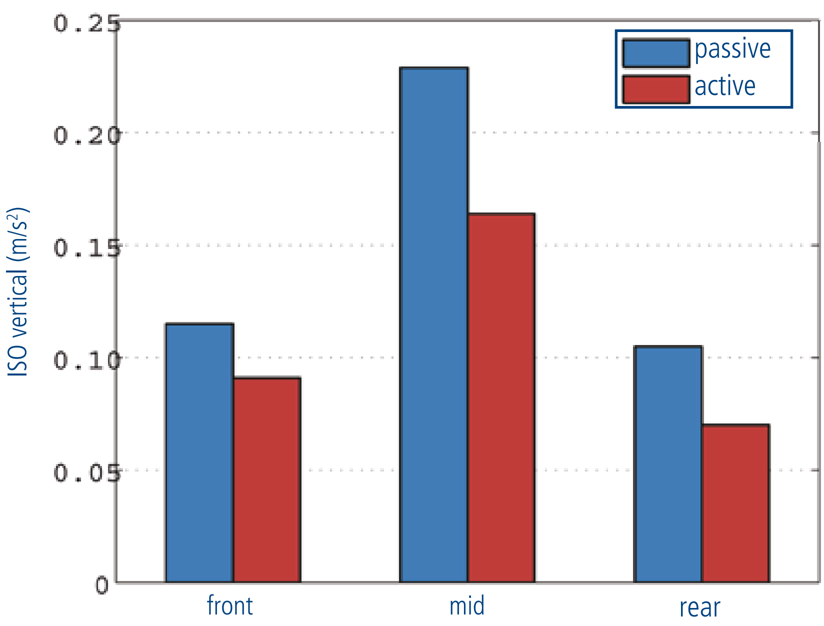

Fig. 4: Vertical ride comfort (ISO 2631) is significantly improved with the active system

SIMULATION RESULTS

Simulations were performed on a straight track section, as well as on a large-radius curve section, at a vehicle speed of 250 km/h. The curve section consisted of a circular curve with radius R = 3.200 m and track cant D = 0.080 m, corresponding to a track plane acceleration of 1.0 m/s². Measured track irregularities were applied as excitations in the simulation model.

Fig. 4 shows the vertical ride comfort on the straight track section, evaluated according to ISO 2631, above the bogies and in the middle of the car body for the passive and active system, respectively. Ride comfort is significantly improved with the active suspension system compared to the conventional passive system. The car body vibrations above the front bogie are reduced by 20 %, in the middle of the car body by 28 %, and above the rear bogie by 33 %.

Fig. 5 illustrates the effect of the quasi-static roll control, showing the relative roll angles between the car body and the front bogie for the passive and the active system, respectively. These simulations are performed in the curved section. The passively suspended car body is inclined outwards in the curve section relative to the bogie plane (negative roll angle), increasing the lateral acceleration felt by passengers. In the active system, the quasi-static roll control reduces the relative roll angle between the car body and bogie — an average of zero relative roll angle is achieved — hence reducing lateral acceleration. In this case, reduction of the relative roll angle with one degree (~0.017 rad) enables a speed increase of approximately 5 % with maintained ride comfort.

FURTHER BENEFITS OF AVS

The AVS system compensates for negative ride comfort effects if the frequency of the

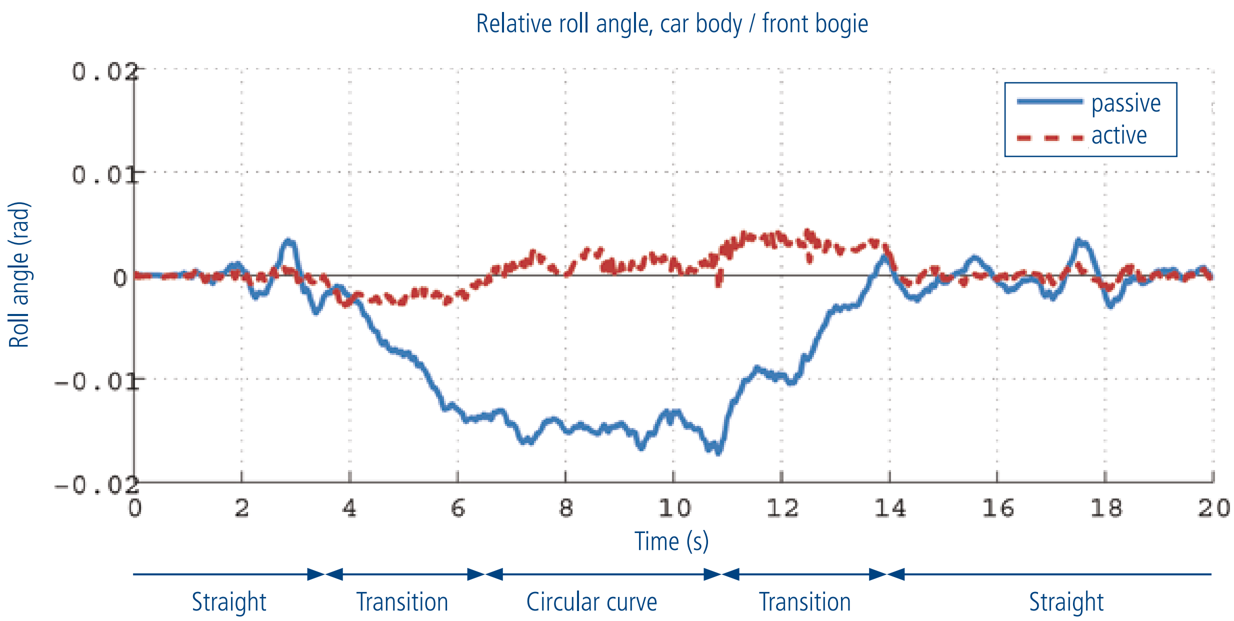

Fig. 5: The active vertical suspension reduces the relative roll angle between the car body and the bogie

first vertical bending mode of the car body is reduced. Generally, a higher frequency of the first vertical bending mode has a positive effect on ride comfort. However, this normally means that the mass of the car body is increased, leading to increased vehicle costs. Fig. 6 shows that ride comfort is negatively affected with decreasing frequency in the passively suspended car body, while remaining generally unchanged in the actively suspended car body. Hence, a lower structural stiffness of the car body can be allowed without negative effects on ride comfort. This means that added elements to stiffen up the car body can be reduced which, in turn, reduces the total car body mass. The mass reduction is less in relation to the stiffness reduction which implies reduced bending mode frequency.

"...a lower structural stiffness of the car body can be allowed without negative effects on ride comfort."

CONCLUSIONS

A simulation model of a one-car Regina vehicle has been used to evaluate the impact on ride comfort by means of active vertical secondary suspension. The conventional vertical dampers in the secondary suspension are replaced by actuators. The control strategy consists of dynamic vertical control as well as quasi-static roll control of the car body.

Simulation results show that vertical ride comfort is significantly improved by means of dynamic control compared to a passive system. Further, quasi-static roll control reduces the relative roll angle between the car body and bogies. The vertical actuators are able to generate car body tilting up to around one degree in curves to reduce the lateral acceleration perceived by the passengers, and hence, allow for higher speeds without negative effects on ride comfort.

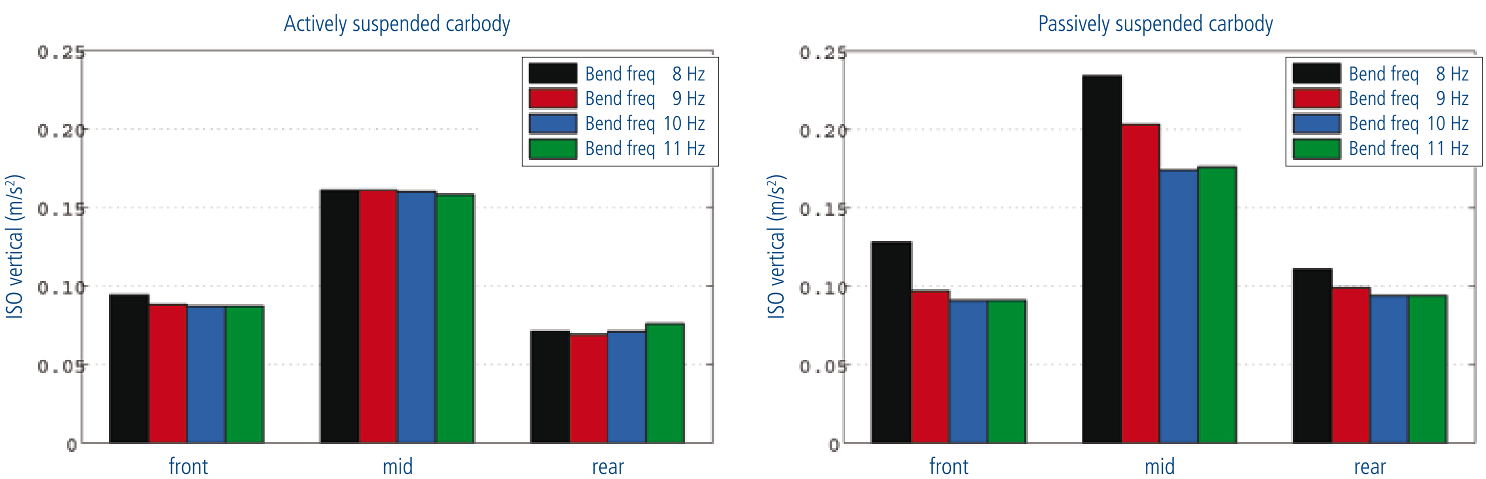

Fig. 6: The AVS system allows for a lower bending mode frequency of the carbody without negative effects on ride comfort