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Ride comfort improvements in switches using active secondary suspension with preview

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Abstract

Trains often have to change their track when entering or leaving a station. This represents a challenging scenario related to passenger ride comfort due to small curve radii in switches. The abrupt change of curvature usually results in a bumpstop contact in the secondary suspension. The paper presents a control strategy with preview information based on stored track data. For this purpose, a calculation method is introduced to determine forces and torques acting on the carbody, e.g. when passing switches in advance. This data can be used by an active lateral secondary suspension in order to prevent bumpstop contact. Corresponding multibody simulations showed promising results. Peak values of lateral acceleration acting on the passengers can be reduced significantly resulting in better ride comfort.

Keywords: active secondary suspension, preview control, ride comfort, multibody simulation, lateral suspension, hold-off device.

1 Introduction

For rail vehicles the secondary suspension provides reduction of dynamic accelerations acting on the carbody and, thus, it is primarily responsible for passenger comfort [1]. To increase the performance limitations of a passive suspension (semi-) active components might be integrated. A comprehensive overview on active suspension is provided in [2]. In the present work our focus is set on ride comfort in lateral direction and the corresponding effects.

For controlling the quasi-static motion of a carbody in order to prevent bumpstop contact when travelling in a curve at high speed the concept of a Hold-off device (HOD) is well known and already in use [3]. Vinolas et al. [4] propose a HOD using pneumatic actuators. In their work a bumpstop contact does not occur, however, a transition curve between tangent track and curve is provided, i.e. the uncompensated lateral acceleration increases linearly. When the vehicle is passing through the diverging route of switches there is an abrupt change of curvature and consequently of lateral acceleration. Usually bumpstop contact can then no longer be avoided.

Basically, the movement of a train is influenced by many factors e.g. crosswind, track irregularities etc. However, when entering small radius curves like switches the dominating impact on movement is due to track layout. If latter is known in advance (e.g. from a track database or measured by a preceding wheel pair) it can be used for improving running dynamics as it is already performed with tilting control [5].

In the project ‘Next Generation Train’ (NGT) the German Aerospace Center (DLR) is developing a mechatronic running gear prototype which is currently built in full scale [6]. For this prototype the effectiveness of lateral guidance control using preview information for reduction of wear has already been proved in [7]. In the present work this strategy using preview data is applied to achieve an increase of ride comfort in track scenarios with small curve radii (e.g. switches). Supposed the train position is well-known the usage of stored track data offers the opportunity to control the lateral position of the carbody. Thus, bumpstop contact can be avoided even in challenging scenarios like the aforementioned one.

2 Methods

In this section we generally describe relevant relations between track characteristics, namely curvature of the track and course angle, and the resulting forces and torques acting on the carbody.

For a train with passive suspension forces are created by suspension deflection. For safety reasons latter has to be restricted by bumpstops resulting in a negative impact on ride comfort [3]. If the track layout is known it is possible to determine forces and torques at a certain track position in advance, e.g. the yaw moment during curve negotiation and centrifugal forces. This offers the opportunity to enable countermeasures with the help of lateral actuators in the secondary suspension in order to minimize lateral offset.

In the present work we assume that the curvature $\kappa(s)$ of the track is given. This input can be generic or measured by a track recording car. A discrete description of the upcoming track is stored in a generic database. Using this track definition, a simplified model travels along the track. A kinematic constraint is set that front and rear bogie ideally follow track (Fig. 1) such that the only remaining degree of freedom of the model is its current position s. Based on curve characteristics it is possible to determine the course angle $\psi(s)$ of the carbody at a certain position, see Fig. 1.

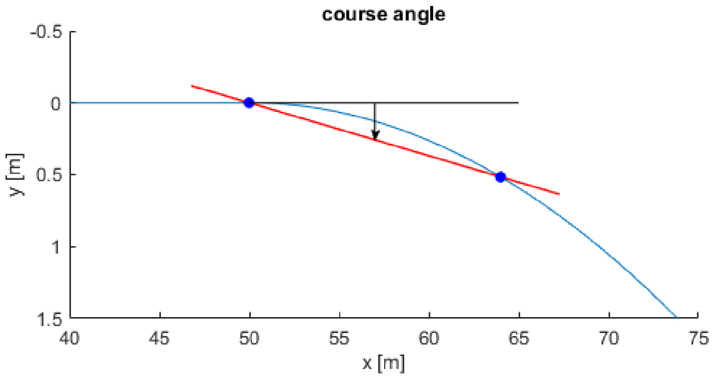

Fig. 1: Determination of the current course angle

It holds that

$$\psi(s) = \int \kappa(s) ds. \tag{1}$$

If the velocity v of the train is constant the second time-derivative of ψ is

$$\ddot{\psi} = \frac{d^2\psi(s(t))}{dt^2} = \frac{d^2\psi}{ds^2} v^2. \tag{2}$$

By multiplying with the carbody's moment of inertia about vertical axis $I_{z,CB}$ one obtains the yaw moment M_{yaw} that acts on the model e.g. when entering a curve. Related to centrifugal force, the assumption is made that centrifugal acceleration a_c depends on mean value of the current curvature at front bogie and rear bogie

$$a_c = \frac{v^2\left(\kappa(s_{BG,fr})+\kappa(s_{BG,re})\right)}{2}. \tag{3}$$

Finally, forces and torques acting on the carbody in order to follow track are determined. This data can be used by active secondary suspension with feedforward control in order to minimize the lateral deflection of the secondary springs. The procedure described above is now applied to a multibody simulation of the NGT. The driving scenario considered is a crossover (Fig. 2). It includes two switches with radius $R = 190m$ separated by a tangential line of length $5m$. The train speed is $10\,\frac{m}{s}$.

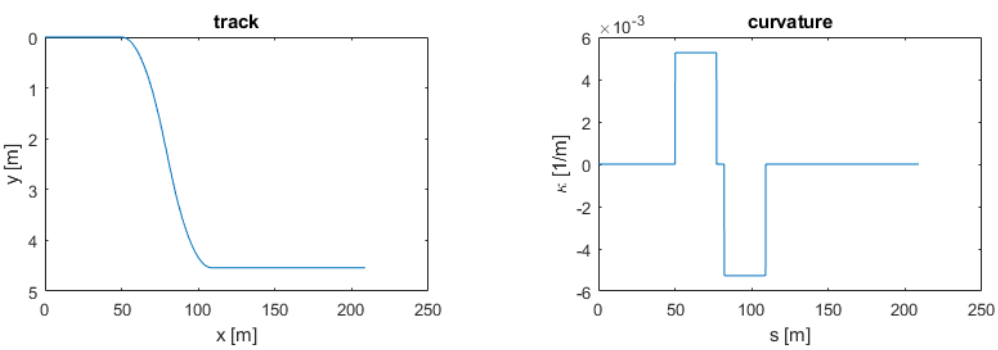

Fig. 2: Driving scenario

3 Results

Fig. 3 illustrates the impact of lateral centering using preview data on lateral acceleration of the carbody. In the left diagram results of a multibody simulation with passive suspension are shown. Lateral acceleration has been measured at three different locations (at carbody's CoG and above front and rear bogie). The diagram on the right shows the results of the same scenario but with our newly developed control using preview data. It can clearly be seen that during multibody simulations with passive secondary suspension a bumpstop contact cannot be avoided in this scenario resulting in peak values of lateral acceleration which worsens ride comfort. In contrast to this, bumpstop does not occur while active lateral suspension presented in this work is active. The maximum acceleration acting on the passengers can be reduced by 65 %.

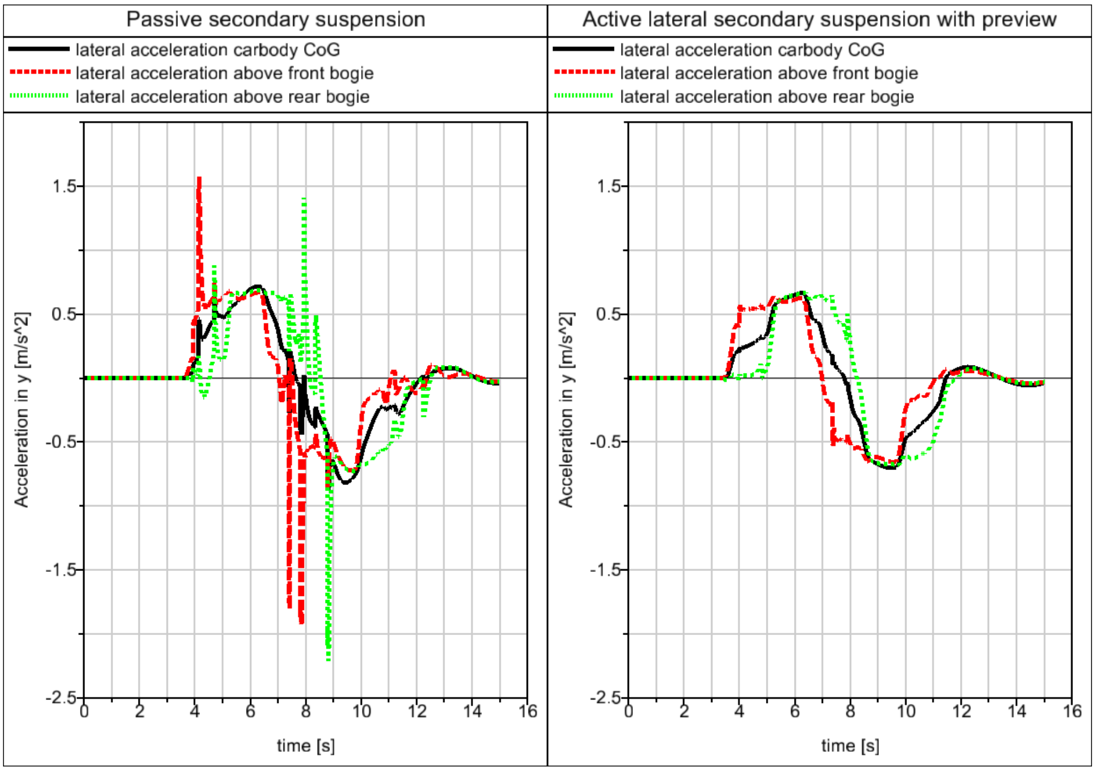

Fig. 3: Carbody lateral acceleration when passing a crossover

Up to now, train position along track is assumed to be known and error free which is not the case in reality. Performance of the presented control strategy depends on a precise and reliable train localisation, for recent research results refer to [8] and [9]. In order to increase the reliability of localisation an inertial measurement unit (IMU) could be mounted on a preceding running gear. For example, the location of a curve entry could be determined by measuring lateral acceleration. In case of unexpected events (e.g. track change due to an occupied track) it is important to note that feedforward control has to be updated. Finally, a sufficiently accurate map is necessary, e.g. measured by a track recording car in advance.

It is worth to mention that lateral deflection of the carbody is still restricted by bumpstops. If there is a malfunction of the system ride comfort could deteriorate but a risk of derailment is not to be expected. Nevertheless, this has to be confirmed by further studies.

4 Conclusions and Contributions

In this work a control strategy with preview is introduced in order to increase ride comfort on track scenarios like passing through the diverging route of switches (i.e. tracks with small curve radii without transition curves). There is an abrupt change of curvature which usually results in bumpstop contact.

To overcome this issue a calculation method is presented which includes a generic database where a discrete description of the upcoming track is stored. Latter allows to determine forces and torques acting on the carbody in order to follow the track in advance. Subsequently, calculated data can be used by active secondary suspension with feedforward control in order to minimize lateral deflection of the secondary springs.

Supposed the train position is well-known this strategy prevents contact with bumpstops in the secondary suspension. Thus, the negative influence of peak values of lateral acceleration acting on passengers can be avoided resulting in a positive impact on ride comfort. Another advantage is the possibility to take time delay of any actuator into account directly supposed the actuator dynamics are known.

The performance of the presented control strategy depends on the reliability of train localisation. For further research it should be investigated to mount an additional inertial measurement unit (IMU) on a preceding running gear in order to perform sensor fusion between several localisation methods. Furthermore, in case of unexpected events (e.g. track change due to an occupied track) it is important to note that feedforward control has to be updated.

Multibody simulations of the NGT using the proposed lateral centering with preview showed promising results. The maximum acceleration acting on the passengers could be reduced by 65 %. The next step is to create a more realistic simulation environment where train localization is not considered error free. Furthermore, experimental tests are performed on DLR’s research facility with a full scale prototype of the NGT running gear [6].

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