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Application of nonlinear stability analysis in railway vehicle industry

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1. Introduction

A heavy oscillation of bogies and wheelsets called instability or hunting constitutes a safety risk to be assessed during vehicle design and development. A dynamical system vehicle/track is always nonlinear, at least due to the nonlinearities in the contact between wheel and rail represented by the saturation of creep forces and nonlinear contact geometry. The vehicle model can also contain nonlinear or non-smooth coupling elements like a clearance in guidance element and bump-stop or friction damping in the suspension. Consequently, the stability analysis of a railway vehicle deals with nonlinear and possibly non-smooth system.

The presented paper deals with use of nonlinear calculations and bifurcation analysis when investigating running stability during vehicle design and development in the rolling stock industry. It answers the questions:

- What is the impact of the limit cycle oscillations on safety and oscillation behaviour of a railway vehicle?
- How do we assess the running stability during railway vehicle design and development?
- What do we know about the bifurcation behaviour of railway vehicles?
- What are the needs and expectations considering the bifurcation analysis and nonlinear stability assessment from the point of view of industrial application?

2. Stability assessment in railway vehicle industry: State-of-the-art, advances and future needs

The paper will show the impact of hunting or instability on the safety and oscillation behaviour of railway vehicles. Whereas a low frequency self-excited oscillation connected with high lateral carbody motions can lead to a deterioration of running behaviour in lateral direction as well as ride comfort degradation, the instability of bogies and wheelsets limits the maximum permissible speed with respect to running safety.

The stability analysis constitutes the most diversified part of running dynamics calculations during railway vehicle development. Methods such as linearised and nonlinear calculations can be applied in various versions. The number of options is also widened by the diversity of input parameters and conditions available, making it difficult to compare and to analyse both the methods and the results of stability calculations. The methods for running stability assessment as they are used in the industrial applications [1] will be presented and compared.

A detailed stability assessment can be realized by a bifurcation analysis [2]. When analysing the stability of railway vehicles, the bifurcation diagram displays amplitude of a limit cycle in function of speed. Two typical situations can result: subcritical Hopf bifurcation (left diagram in Figure 1) or supercritical Hopf bifurcation, (right diagram in Figure 1). In case of subcritical bifurcation there is a speed range at which the solution can "jump" between a stable damped movement and a limit cycle depending on the initial conditions or the excitation amplitude.

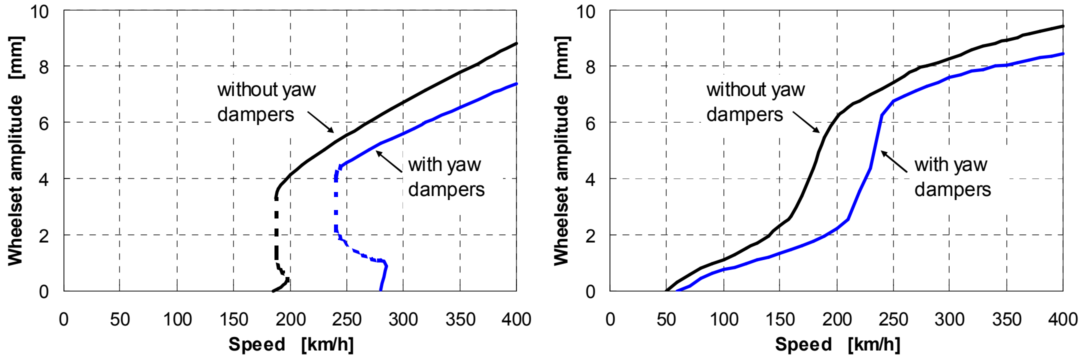

Figure 1: Bifurcation diagrams of a double-decker coach for two different wheel/rail contact geometries

Author’s investigations [1], [3] demonstrate the relation between the nonlinearities of the system vehicle/track and the type of bifurcation diagram. The nonlinearity of the contact geometry wheelset/track dominates the kind of Hopf bifurcation at vehicles without nonlinearities affected during a run on straight track, which is usually the most critical case from the stability point of view. A subcritical Hopf bifurcation can usually be observed at vehicles with conical wheels or a combination wheelset/track with the equivalent conicity increasing with lateral wheelset amplitude, whereas the combination wheelset/track with a decreasing conicity in function of amplitude results in the supercritical Hopf bifurcation. The nonlinearity of vehicle model can supersede this effect of wheel/rail contact and change the type of bifurcation. Figure 2 shows as example the influence of nonlinear, non-smooth characteristic of yaw dampers on the bifurcation diagram of a double-decker coach modelled in simulation tool Simpack. The damping force of yaw dampers is nonlinear due to a strong slope reduction at the blow-off force. The yaw damper characteristic No. 3 in Figure 2 assumes a negligible force for a very small piston velocity, caused e.g. by a piston leakage. The variation of the blow-off force and the non-smooth characteristic of yaw damper result to a change of the Hopf bifurcation and to variation of critical speed between 200 and 280 km/h.

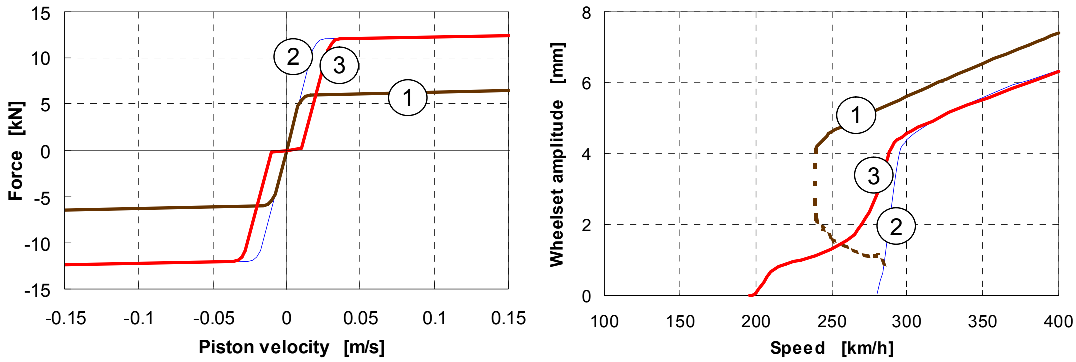

Figure 2: Influence of yaw damper characteristic (left diagram) on the bifurcation (right diagram)

The bifurcation analysis allows gaining a valuable output regarding the vehicle behaviour at the stability limit, however it is time consuming and rather rarely used in the engineering praxis. Because of large variation of service conditions and parameters, a large set of investigations for different conditions is required during the vehicle design in the rolling stock industry. The railway vehicle industry would require a robust procedure, which could be less exact, but allow a fast calculation of bifurcation diagrams using a complex, realistic multi-body vehicle models, for a set of different conditions wheelset/track and vehicle parameters (a "rough and robust" assessment for a large set of input parameters).

3. Conclusions

An advanced nonlinear railway vehicle stability assessment can be realised by bifurcation analysis. The type of Hopf bifurcation is determined by the nonlinearities in the system vehicle/track. Author's latest investigations [1], [3] describe the typical effects of wheel/rail contact and nonlinearities of the vehicle model and allow an estimation of the type of Hopf bifurcation without a detailed bifurcation analysis. However, due to nonlinear and sometimes also non-smooth coupling elements, a complete stability assessment could be achieved only by the bifurcation analysis. To allow an efficient application of the bifurcation analysis during the rolling stock design and development in the railway industry, a fast and robust algorithms or procedures are required which could be applied in frame of commercial simulation tools.

4. References

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