#06 Curving and Stability Optimisation of Locomotive Bogies using Interconnected Wheelsets

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The trade-off between curving and stability is a well known challenge concerning railway vehicle dynamics. Bogies with longitudinally soft axle guidance are suitable for curved track, whereas good stability performance can be achieved with stiff axle guidance. When using a conventional design, the vehicle performance is a compromise between curving and stability demands. Improvement can be achieved by the cross coupling of wheelsets as realised on various bogie types, e.g. on three piece bogies (Scheffel bogie). In the case of locomotives and traction vehicles, the axle guidance usually transfers the tractive force. To design self steering interconnected wheelsets for locomotives, the transfer of tractive forces between the wheelsets and bogie frame has to be separated from the axle guidance system.

A solution with a wheelset cross coupling mechanism with separation of axle guidance and tractive force transfer was developed and realised on the Locomotive Series 460 of the Swiss Federal Railway Company [1]. The mechanical scheme of the mechanism is shown in Fig. 1. The design of the steering mechanism uses frictionless rubber elements with finite stiffness.

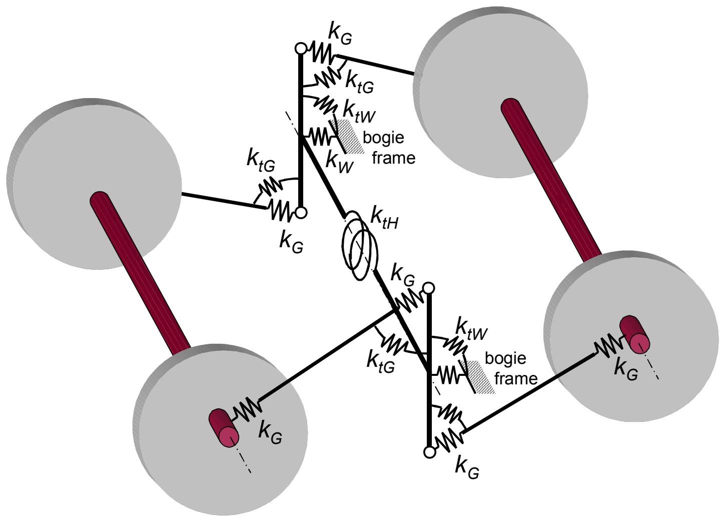


Fig. 1. Scheme of coupling mechanism between the wheelsets.

The interconnected wheelsets of a two-axle bogie can move in the horizontal plane in four eigenmodes (Fig. 2):

- shearing mode (S)
- bending (steering) mode (B)
- tractive (longitudinal in phase) mode (T)
- longitudinal anti-phase mode (L).

When analysing only one eigenmode, the stiffness of coupling between wheelsets can be expressed as an equivalent longitudinal stiffness between the axle box and bogie frame, e.g. k_{eB} for the bending mode. The total equivalent longitudinal axle guidance stiffness for bending mode then comprises

$$k_{xB} = k_{Px} + k_{eB}$$

with k_{Px} - longitudinal axle guidance (primary suspension) stiffness (per 1 wheel).

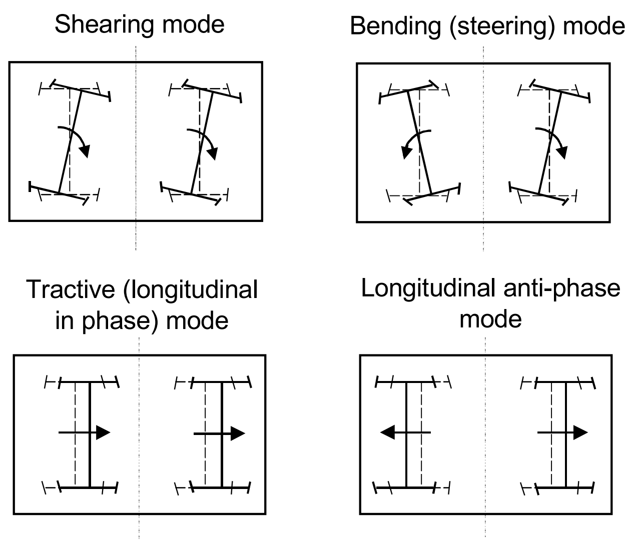
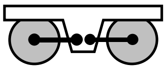


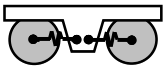
Fig. 2. Wheelset eigenmodes of a two-axle bogie.

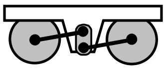
The self-steering ability and curving properties of a bogie are directly related to the equivalent longitudinal guidance stiffness k_{xB}. Therefore this parameter is used for preliminary analysis of curving and stability performance of the investigated bogie.

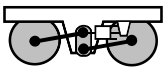
To achieve good self-steering ability together with high speed stability and high tractive forces, the equivalent longitudinal stiffness of the coupling mechanism must be low for bending mode (k_{xB}), but high for other eigenmodes. This can be achieved by low torsional stiffness, but high radial stiffness of rubber elements. The torsional stiffness of the coupling shaft should be as high as possible to reduce the risk of low damped oscillations in the longitudinal anti-phase mode.

The design of the wheelset coupling mechanism described above was integrated into a newly developed bogie for the Multi-System-Locomotive of Bombardier Transportation. The locomotive bogie is based on the well proven flexifloat bogie family concept [2]. The modular axle guidance system allows the construction of four axle guidance versions based on specified service conditions [3]:


⇨ longitudinal stiff axle guidance (ST)


⇨ longitudinal soft axle guidance (SO)


⇨ longitudinal very soft axle guidance combined with wheelset coupling shaft (CW)


⇨ longitudinal very soft axle guidance combined with wheelset coupling shaft and dampers of coupling shaft (CWD)

Using the coupling shaft mechanism with and without dampers, the following improvements can be achieved:

- self-steering ability and radial adjustment in curves, together with reduction of wheel-rail guiding force and wear
- transfer of tractive force without influencing the self-steering ability of the wheelsets
- increasing the critical speed to the same range as bogies with stiff axle guidance.

Based on the total equivalent longitudinal axle guidance stiffness for the bending mode k_{xB}, the influence on the stability and curving performance of the locomotive with four different versions of axle guidance was evaluated as shown in Fig. 3. The reduced equivalent stiffness k_{xB} of the wheelset guidance with coupling shaft and dampers of coupling shaft (CWD) achieves significantly reduced guiding force and wear index retaining similar level of stability as the version with longitudinal stiff axle guidance (ST).

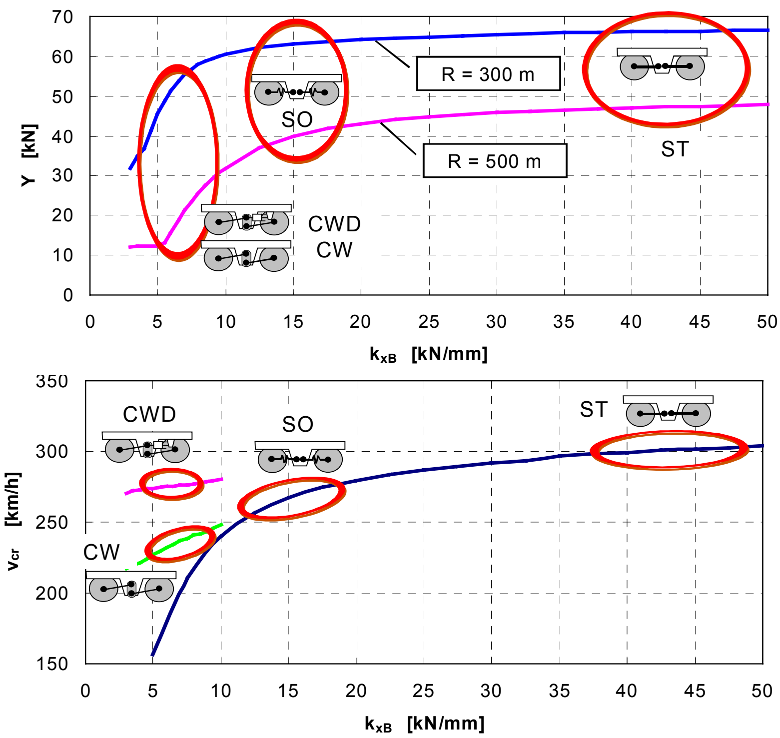


Fig. 3. Guiding force in curve (above) and critical speed (below) as function of equivalent longitudinal axle guidance stiffness. Marked areas display recommended equivalent stiffness for the proposed versions of modular axle guidance.

As the radial adjustment of the wheelsets in curves is achieved through creep forces in the contact between wheel and rail, the running characteristics are influenced by the conditions in the contact. Therefore, a role is played not only by the curve radius and cant deficiency but also by geometry of the wheel and rail profiles or by the tractive effort exercised by the locomotive. These influences were analysed comparing computer simulations of the locomotive with longitudinal stiff axle guidance (ST) and longitudinal very soft axle guidance with wheelset coupling shaft and dampers (CWD). As example, Fig. 4 illustrates the influence of rail inclination. In the case of rail profile S 1002, which is optimised for the rail inclination 1:40, the guiding forces and wear are somewhat higher at an inclination of 1:20. However, when the versions with the stiff and very soft wheelset guidance are compared, the advantages of the self-steering bogie are clearly apparent. Fig. 5 shows the influence of the locomotive tractive effort. With increasing tractive force the steering decreases, the difference between stiff and self-steering bogie is smaller, but the self-steering bogie achieves still better curving performance than the conventional bogie with stiff wheelset guidance.

Similar conclusions can also be reached in other comparisons - it is true that the radial adjustment of the self-steering wheelsets in curves is influenced through varying factors, but a self-steering bogie always achieves better running characteristics on tracks with numerous curves than the conventional bogie construction with stiff wheelset guidance. This conclusion was already proven in the service too: On the Gotthard route the locomotive SBB Re 460 achieves 3 to 4 times longer running performances between re-profiling of the wheelsets than previous locomotive versions [4].

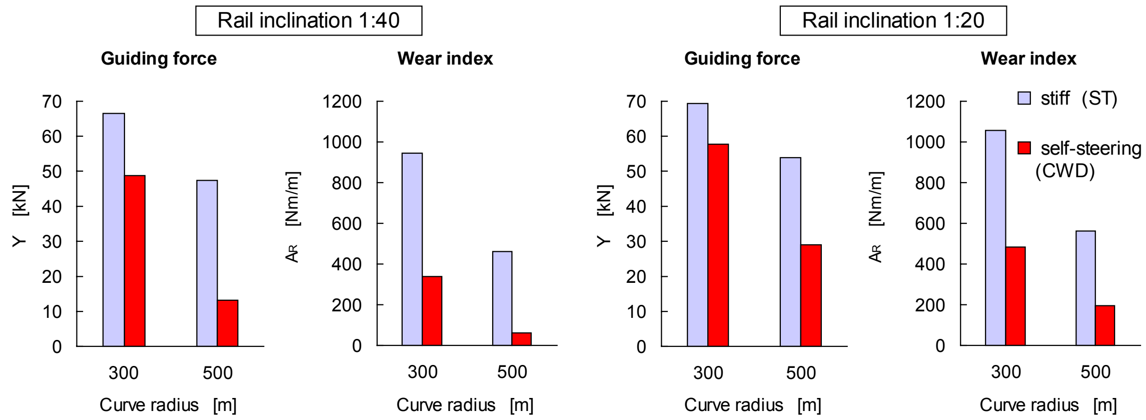


Fig. 4. Influence of rail inclination on the guiding force and wear index of the outer leading wheel in a curve.

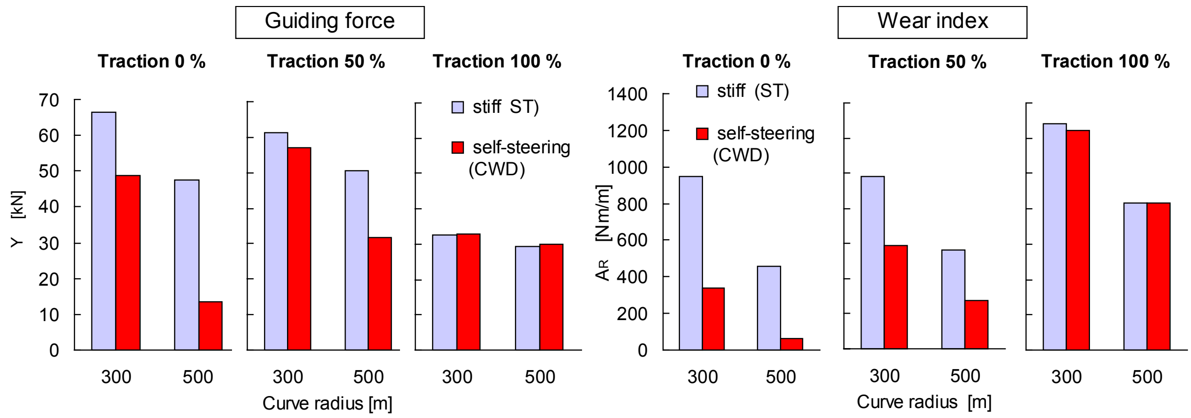


Fig. 5. Influence of tractive effort (% of the maximum tractive force) on curving performance (outer leading wheel).

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