

# Bogie design for better dynamic performance

## Example of a locomotive bogie

❖ Dr.-Ing. habil. Oldrich Polach, Chief Engineer Dynamics, Bombardier Transportation, Bogies, Europe

*A technological challenge with respect to railway vehicle bogies is the conflict of objectives between running stability and curve negotiation. The wheelset coupling mechanism used in modular axle guidance of a newly developed locomotive bogie deals excellently with this conflict. This article presents the design principle of this bogie and simulation results related to running stability and curving performance.*

Computer analyses and simulations of vehicle dynamics play an integral part in the design processes of the Engineering Team of Bombardier Transportation. Already at an early stage, the computer simulations are subjected to concept investigations and integrated into advanced technology projects. The main part of the dynamic calculations take place during the Tender Phase, the Preliminary Design Phase, and the Detail Design Phase of the engineering process. The vehicle type test and field support is also aided by vehicle dynamics analysis if required. A basic requirement for efficient and reliable dynamic analysis is a software package, which provides extensive possibilities for the modelling and calculation of multi-body systems whilst at the same time enabling easy application and visualisation options (see Fig. 1). The simulation tool and the dynamic analysis procedure have been standardised in order to facilitate the efficient and

effective international collaboration of the individual business units, groups and sites. During the dynamic analyses and computer simulations, running safety, track loading, ride characteristics and ride comfort of the vehicle are the primary items of investigation. These are the characteristics which are tested during the on-track test as part of the vehicle acceptance procedure.

During their development phase, the bogie and vehicle parameters have been extensively optimised with the aid of dynamic calculations. Conformity with the limiting values stated in the norms and regulations as well as the vehicle specification has also been examined. In addition, other important factors such as stresses and cumulative load distri-

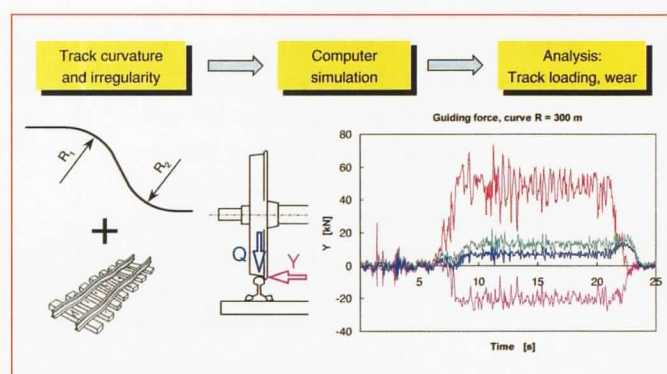


Figure 2. Computer simulation of curve negotiation

bution, spring displacements, vehicle gauging, influence of the braking and tractive effort, side wind stability etc. have been taken into consideration.

### Conflict between stability and curving

During curving (Fig. 2) the vehicle is guided in the travelling direction by the rails. Although the conical form of the wheel tread profile partially eases curve negotiation, forces arise from the contact between wheel and rail in a lateral direction. These guiding

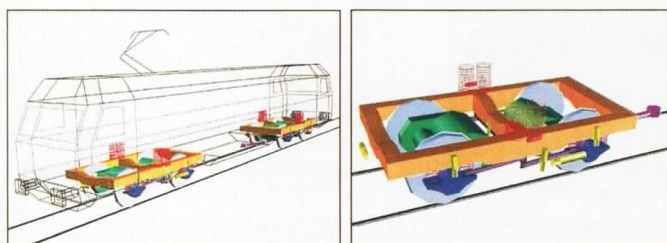


Figure 1. Visualisation possibilities of modern simulation tools: Model of the Multi-System Locomotive for vehicle dynamic calculations



forces (which cause rail loading and wear to the rail and wheel) can reach very high values, particularly when heavy vehicles such as locomotives run through narrow curves (see Fig. 1). The simulations, which take the track curvature and irregularity into consideration, allow the values of rail loading to be determined in advance and enable optimisation of the vehicle parameter.

The lateral wheel profiles enable self-centring of the wheelset. However, they are also a cause of wheelset running instability (so-called “hunting”) - a self-exciting non-damped oscillation characterised

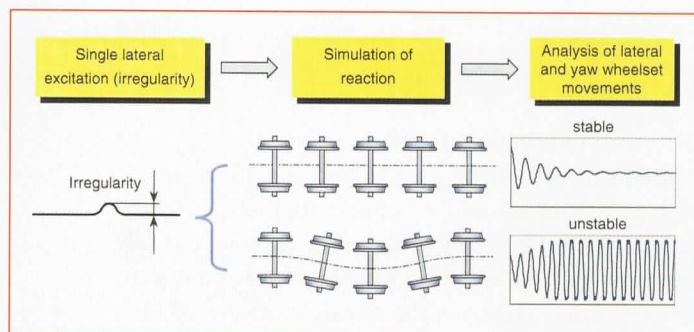


Figure 3. Running stability of a wheelset

by a coupled lateral and yaw motion of the wheelset. The wheelset guidance by the spring elements between the wheelset and the vehicle frame suppresses this phenomena and allows stable running up to the critical speed. Above the critical speed, even minor lateral excitation leads to oscillations of increasing amplitude (Fig. 3). The stability analysis for optimisation of the construction parameters and investigation of the stability play a significant part in the dynamic tests of the bogies.

The conflict of objectives between running stability and curving performance is a well-known technological challenge with respect to railway vehicle dynamics. During the wheelset guidance design phase, the contradictory objective arises of achieving running stability at high speed, whilst fulfilling the requirement for low wear and insignificant wheel-rail forces in curves. For instance, Fig. 4 demonstrates with a locomotive bogie the guiding force of the leading wheelset in curves and the critical speed on straight track, both as a function of the longitudinal stiffness of the wheelset guidance. It is true that both values cumulate with increasing stiffness, but the objective differs, as the guiding force in curves should be as low as possible, whilst that of the critical speed should be high. An increase in stability through

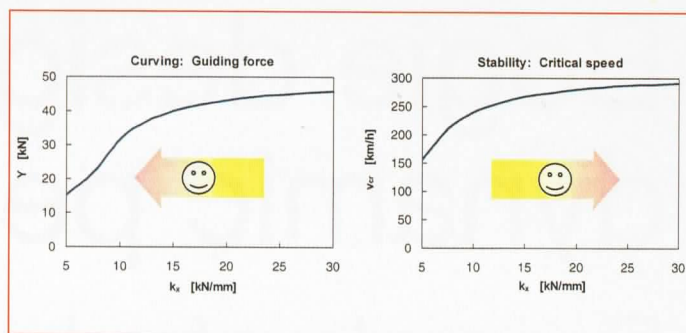


Figure 4. Conflict in objectives between stability and curving during the design of the wheelset guidance

wheelset guidance stiffness leads to deterioration of the running characteristics in curves and vice versa. Bogies with longitudinally soft wheelset guidance are suitable for curved track, whereas good stability performance can be achieved with stiff wheelset guidance. When using a conventional design, the vehicle performance is a compromise between curving and stability demands.

### Self-steering bogies

Is further optimisation possible? In order to investigate this, let us take a look at the dynamic properties of wheelsets in the horizontal plane. The wheelsets of a two-axle bogie can move in the horizontal plane in four eigenmodes, Fig. 5:

- shearing mode (in phase wheelset rotation about vertical axis)
- bending (steering) mode (anti-phase wheelset rotation about vertical axis)

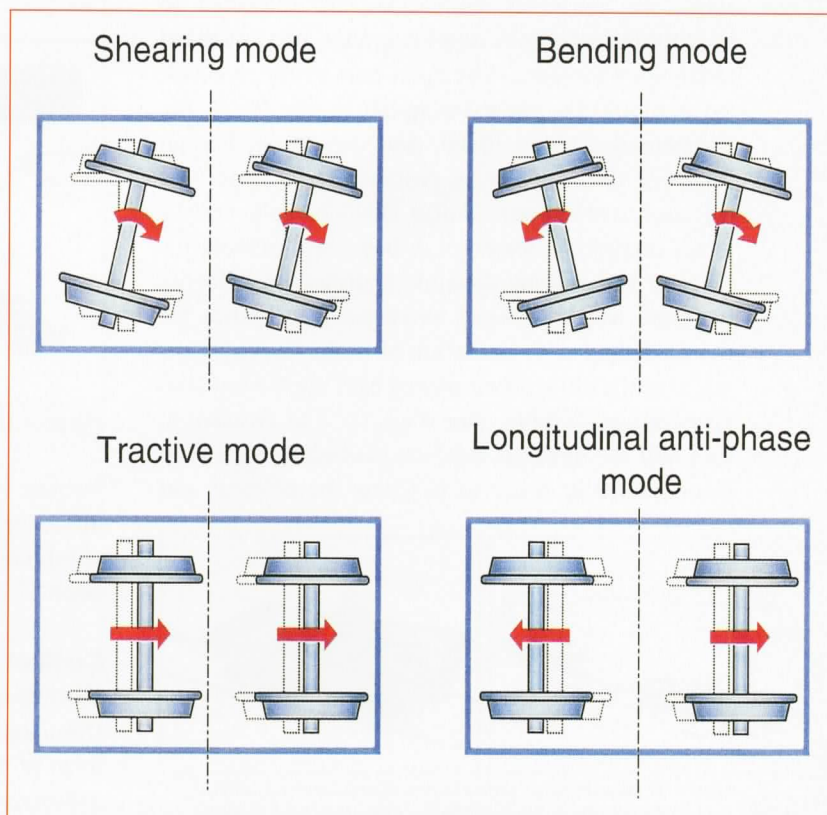


Figure 5. Wheelset eigenmodes of a two-axle bogie

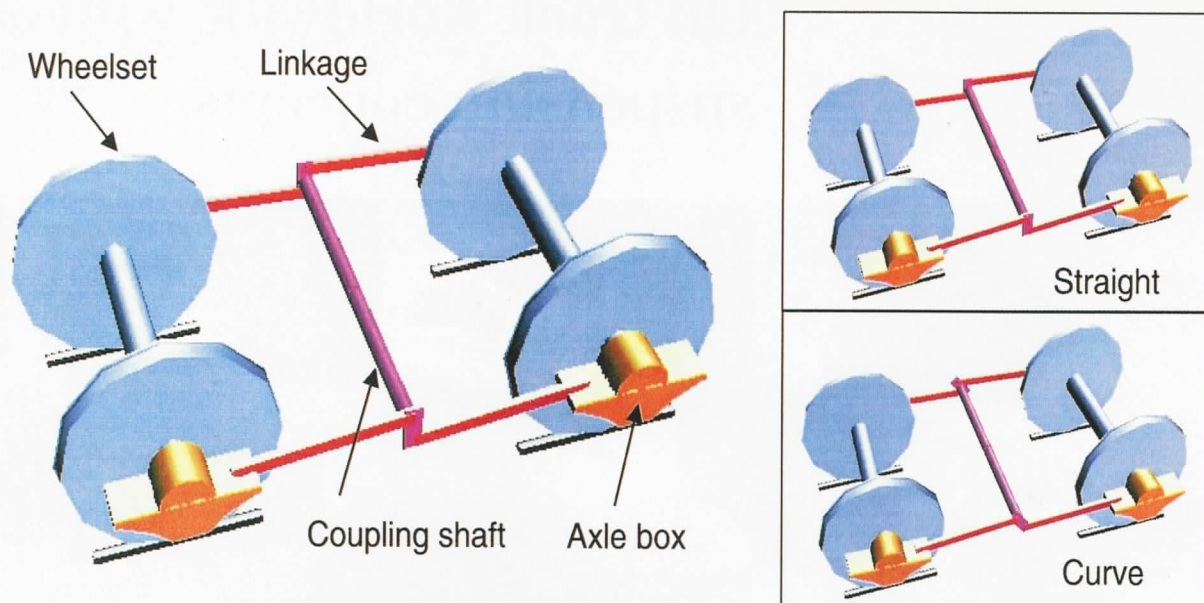


Figure 6. Coupling mechanism of the wheelsets by way of coupling shaft

- tractive mode (longitudinal in phase movement of the wheelsets)
- longitudinal anti-phase mode (longitudinal anti-phase movement of the wheelsets).

To achieve a self-steering ability together with high speed stability and high tractive forces, the system stiffness must be low for bending mode, but high for shearing eigenmode. The longitudinal eigenmodes should be stiff to allow the transfer of braking forces and tractive forces of traction vehicles between the wheelsets and bogie frame without large movements. High shearing stiffness paired with low bending stiffness, characterised by a bogie construction tending towards curves, can only be achieved by additional coupling between the wheelsets.

This constructional design, so-called “cross-coupled self-steering bogies” has been realised on several bogies. An overview of the various designs can be seen in [1]. A description of some self-steering bogies from Bombardier Transportation is given in [2] and [3].

#### Locomotive bogie with modular wheelset guidance

Through the development of a new locomotive bogie, the Flexifloat Bogie Family of Bombardier Transportation [4] has been complemented with the proven wheelset coupling mechanism with separation of axle guidance and tractive force transfer as demonstrated by the Locomotive 2000 series [5]. The principle of the wheelset coupling by way of coupling shaft, as developed by the erstwhile SLM Swiss Locomotive and Machine Works in Winterthur, now a part of Bombardier Transportation, is illustrated in Fig. 6. This construction operates with

great success in Switzerland (SBB Re 460, BLS Re 465), Norway (NSB El 18), Finland (VR Sr2) and in China for the Kowloon-Canton Railways Corporation (KCRC).

The coupling shaft mechanism fulfils several functions simultaneously:

- heightened stability
- transmission of tractive and braking forces between the wheelset and bogie frame
- achievement of better wheelset adjustment in curves.

According to the required speed level, the new locomotive bogie can be realised with two drive options :

- a fully suspended motor with a hollow shaft around the wheelset axle
- a nose suspended motor.

The wheelset guidance is of modular construction and can be produced in the following versions :

- stiff wheelset guidance (ST)
- soft wheelset guidance (SO) – partially self-steering wheelsets
- very soft wheelset guidance with coupling shaft (CW) – self-steering wheelsets
- very soft wheelset guidance with coupling shaft, supplemented with two coupling shaft dampers (CWD) – self-steering wheelsets with higher stability limit.

By utilising the modular wheelset guidance, a significant differentiation in operational applications can be achieved; from high speed on mainly straight tracks to operation on tracks with a large number of small curve radii.



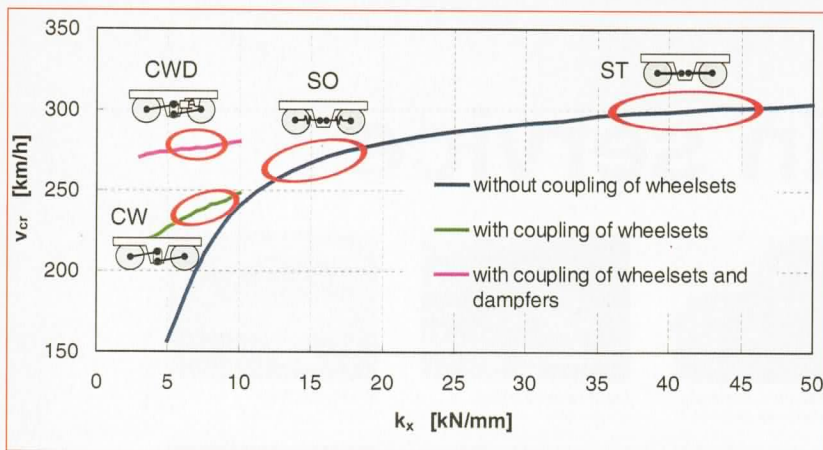


Figure 7. Linearised stability analysis: Critical speed in function of the longitudinal stiffness of the wheelset guidance

A comparison of the versions in respect to stability illustrates the results of the linearised analysis. Fig. 7 shows the critical speed at which the residual eigendamping reaches the limit of 5%, dependent on the equivalent longitudinal stiffness  $k_x$  of the wheelset guidance. The stiffness  $k_x$  takes into account the influence of the primary suspension as well as the longitudinal wheelset guidance linkage and, in the case of the version with interconnected wheelsets, the influence of the coupling mechanism converted to an equivalent value per wheel. With lessening stiffness of the wheelset guidance, stability also declines. In the case of soft wheelset guidance the coupling of the wheelsets increases the critical speed. By damping of the coupling shaft a further increase will be achieved so that, even in the case of very soft wheelset guidance, the stability is comparable with the stiff wheelset guidance.

The advantage of the soft wheelset guidance and the coupling of the wheelsets becomes apparent during curve negotiation. The influence of the

equivalent longitudinal stiffness  $k_x$  of the wheelset guidance on running behaviour in curves is illustrated by Fig. 8 and 9. Both the guiding force of the leading wheel and the wear index decrease with sinking stiffness. Particularly when rail loading by lateral guiding forces has to be reduced, a very soft wheelset guidance becomes necessary. The version with the coupling shaft mechanism, possibly supplemented with coupling shaft damping, deals excellently with the conflict in objectives between stability and curve negotiation. Very low forces between wheel and rail, and lower wheel and rail wear in curves are achieved, whilst retaining speeds on straight track. As the radial adjustment of the wheelsets in curves is achieved through creep forces in the contact between wheel and rail, the running

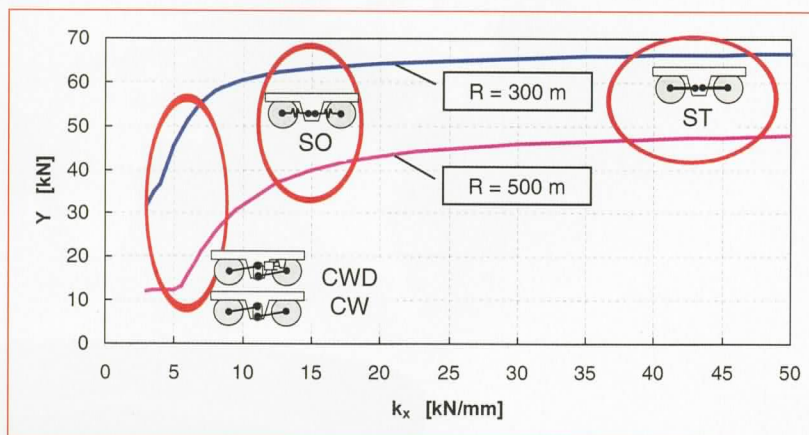


Figure 8. Simulation results of curving: Guiding force of the leading wheel

characteristics are influenced by the conditions in the contact. Therefore, a role is played by the geometry of the wheel and rail profiles [6] or the tractive effort exercised by the locomotive [7]. For example, the influence of the rail inclination in the case of international traffic should be considered (e.g. between Switzerland with a rail inclination of 1:40 and Italy with 1:20). Fig. 10 illustrates the guiding forces between the wheel profile S 1002 and the rail UIC 60 with inclination 1:40 and 1:20. In the case of rail profile S 1002, which is optimised for the rail inclination 1:40, the guiding forces 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 with very soft wheelset guidance and with the mechanism of the coupling between the

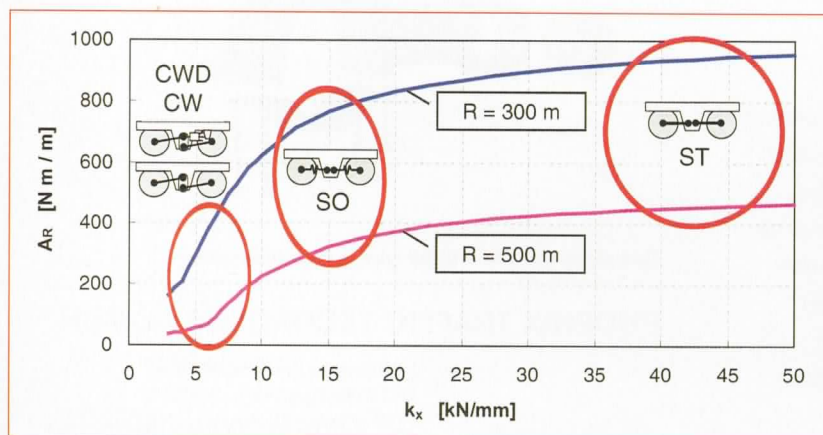


Figure 9. Simulation results of curving: Wear index (friction work per meter)

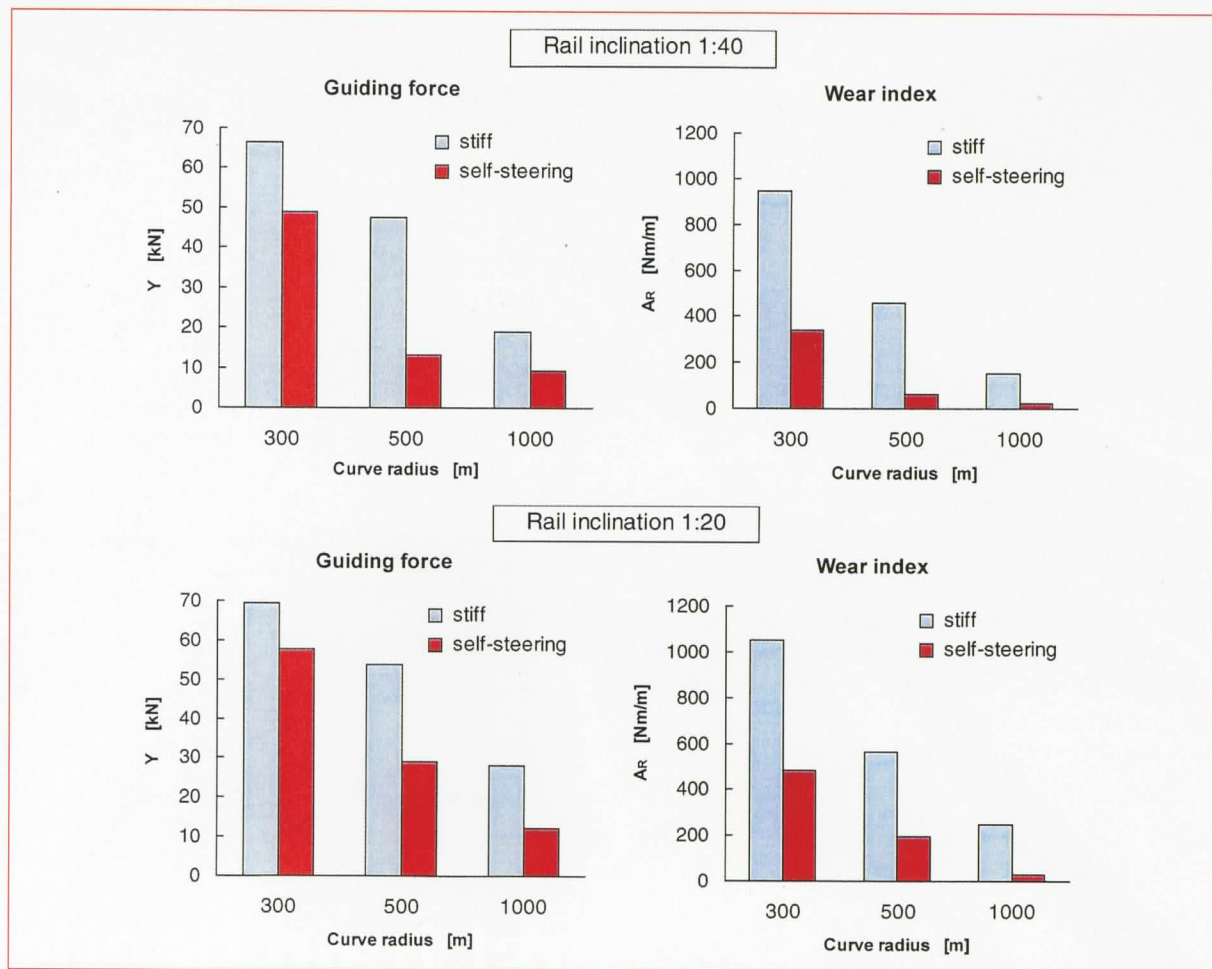


Figure 10. Influence of the rail inclination on the guiding force and wear index of the leading wheel in curves

wheelsets are clearly apparent. 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.

### The advantages of locomotive bogies with modular wheelset guidance

The presented dynamic simulation analysis of the newly developed locomotive bogie demonstrates how the conflict in objectives between stability and curving can be optimised, so that a definite improvement of bogie running characteristics during curving can be achieved. Bogies with self-steering wheelsets significantly reduce wheel-rail wear and guiding forces in curves. These characteristics have not only been confirmed with computer analyses, but also during operation. For example, on the Gotthard route the locomotive SBB Re 460 [5] achieves 3 to 4 times longer running performances between re-profiling of the wheelsets than previous locomotive versions [8].

The influence of vehicle construction on the cost of the track maintenance has been examined by Veit [9] based on 8 different locomotives of the ÖBB (Austrian Federal Railways). According to this study, a locomotive with coupled self-steering wheelsets only causes approximately 60% of the annual expense of the track maintenance in the curves with radius between 250m and 400m when compared with other conventional locomotives with stiff wheelset guidance. The explanation for this can be found in the combination between track maintenance and track loading. According to [9], rail replacement caused by rail wear depends practically 100% on the quasi-static guiding force  $Y$ , and grinding of rails and replacement of sleeper-pads amounts to 90% on this force. Optimisation of the vehicle characteristics in curves can therefore clearly reduce the required amount of track maintenance. In the investigation [9] these influences were extrapolated in two scenarios at an ÖBB railway network. For the examined main network of the ÖBB (travelled on by 400 locomotives with 30 years life time) the evaluation results in differences of 5 to 10% of the invested costs of the locomotives.



## Conclusion

Optimisation of the bogie construction can result in significant cost reductions in relation to maintenance of track and vehicles. The computer analyses and simulations of vehicle dynamics enable examination and optimisation of the bogie and the vehicle characteristics already during the design process, which in turn results in better characteristics as demonstrated by the locomotive bogie described in this article ■

## Literature:

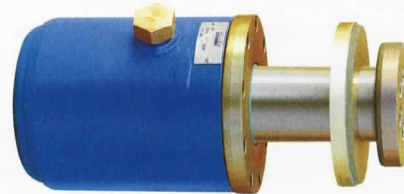
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