Optimization of Construction of Wheelset Drives Used in Modern Railway Vehicles

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Abstract

This text deals with modern railway drives dynamics. It includes ways of its solutions, the main influences and consequences on a vehicle ride. The objective of this text is to describe a current level of knowledge, significant problems and current research results.

Key words

Railway vehicles, transportation, speed, wheelset, dynamics, torsional oscillations, rolliers moment, mechatronics, slip, wheel rail contact, drives, asynchronous motors, tractive effort, traction characteristic, simulation, SIMPACK, Simulink

1. Introduction

The intense electrotechnics development used in railway vehicles during last decades allowed us to install a high power into relatively small vehicles. Asynchronous electric motors being controlled via semiconductor converters offer a considerably simple way how to run those machines with respect to costs, power and weight.

But high performances and high tractive efforts reveal new problems of dynamics events which can occur in drive that aren‘t well known nowadays. A great problem of recent days is a phenomenon called „Torsional Oscillation“ which can lead to defect occurance in wheelset axles and decrease their durability.

This article is about the current research and ways of its solutions.

1.1 History

Torsion oscillations have became well-known in September 2009. The begining of this issue was discovery of a press fitted wheel disc which slightly revolved towards the axle shaft on one of the DB145 locomotive (TRAXX family, see Fig. 1.) [2].

Fig. 1. *DB145 TRAXX locomotive [8]*

During maintenance checks and further investigations on DB145 there were discovered about ten another cases of relative rotation. Although there is currently circa six thousand DB145 locomotives in service, amount of ten problems discovered is significant according to its seriousness.

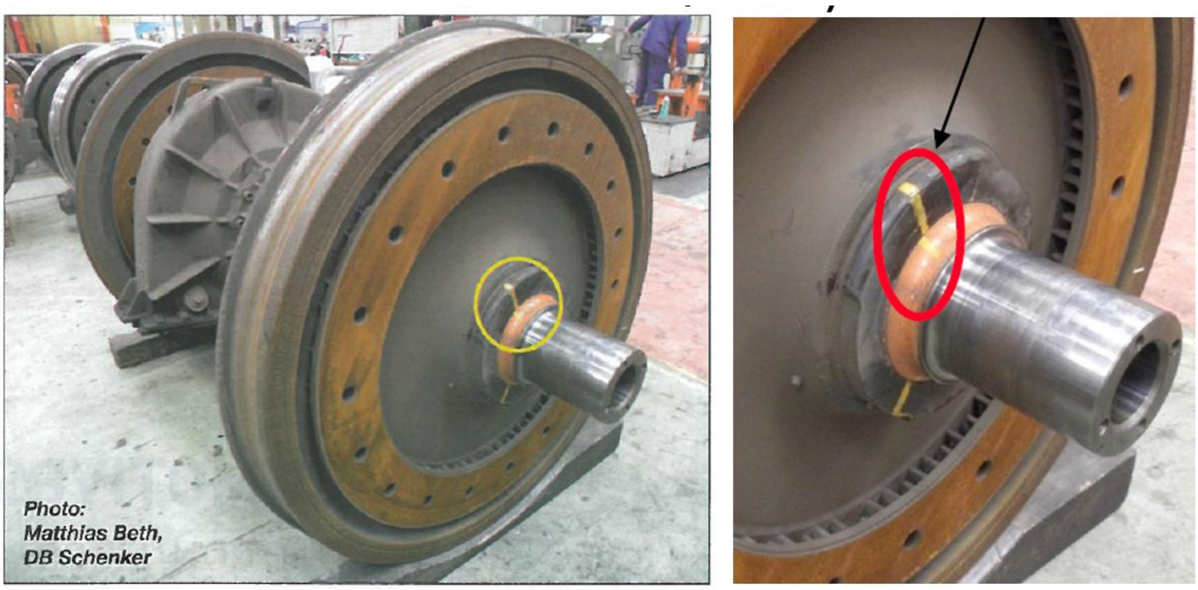

Fig. 2. *Wheel disc relative rotation detail [4]*

Realtive rotation between wheel and axle means losing of friction in press fitting. It means that a wheel can move in this moment almost freely along the axle in transversal direction and make vehicle derailed.

Although there have been no manufacturing problems or failures found, attention has been given to torsion oscillations and its possible consequences.

1.2 Phenomenon description

Torsional oscillation is a situation when both of the wheels start to oscillate one against another. This event leads to slightly twisting of the axle (see Fig. 3.). This can happen because of two wheels representing mass with high inertia are connected together via relatively slim axle representing torsional spring. Thanks to this it is possible to understand the wheelset as a dynamical system with a specific number of degrees of freedom and natural frequencies.

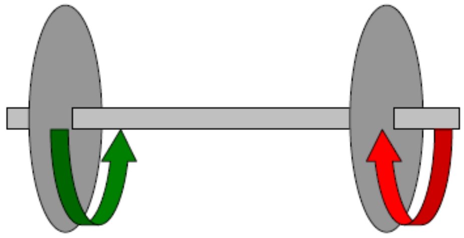

Fig. 3. *Schematic of torsion oscillations [4]*

There are more reasons why this happens.

Well known is a situation when railway vehicle passes through a small radius curvature. During this the outer wheel tends to spin slower than it should whereas the inner wheel revolves faster than it should. The same situation occurs for example in automotive where this is solved via differential gearbox. Railway vehicles usually have no differential gearbox so this is compensated through railway wheel conicity. But this works only in limited range of curvature radius – the smaller the radius is the harder is to compensate different wheel perimeter speeds. Thanks to this the most lightened wheel loses its adhesion and slips and the wheelset starts to oscillate. Example of this is a tram passing through a small curvature radius and emitting some high frequency sounds.

Another reason is overcoming the limit of adhesion thanks to high torque transmitted through the rail-wheel contact. When adhesion is lost on one of the wheel, this wheel loses its possibility to transfer tangential forces. After that the wheel slightly rotates forward. Thanks to this the preload in the axle decreases as well as the tangential transfered force decresaes so the wheel renews its adhesion contact. During this the other wheel must transfer the whole wheelset torque. But there is no posibility of transfer and this wheel slips too. It results in a situation when the first and the second wheel alternately slips. [2]

2. Current knowledge level

2.1 Adhesion

Adhesion is a fundamental aspect of a railway vehicle ride. Friction between wheel and rail allows to transfer tangential forces propelling the vehicle forward (we usually speak about a tractive effort). The value of adhesion expressed mainly via friction coefficient has a lot of boundary conditions and influences for example materials, surface quality etc. Adhesion also depends on vehicle velocity and mainly on a value called a relative slip which is responsible for force transmission. It is just the value of a slip determining if the wheel rolls (the operating point is located in rising part of slip characteristic) or is in a state of clean slippage (the operating point is located in decreasing part of slip characteristic) when losing its possibilty of force transfer, see Fig. 4 [5].

Source of many problems is reaching the limit of adhesion. It is the reason why adhesion and its maintaining is one of the main aims of the authors doctor thesis, as well as this paper and work many others research teams worldwide.

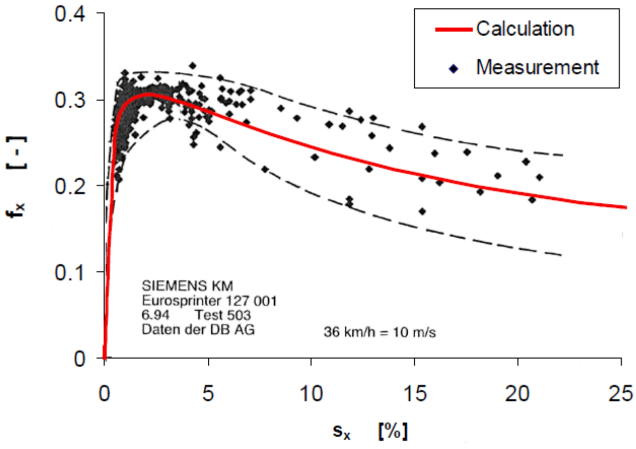

Fig. 4. *Slip characteristic – measured (black) calculated (red) [6]*

2.2 Railway vehicles drives

Drive is the basic part of every driving railway vehicle. Its main part is a motor linked with gearbox transfering torque to the wheelset.

Driving the vehicle on a real track is realted with vibrations created in rail wheel contact. From the begining of railway transportation has been well known that vibrations may negatively influence the state and durability of drives themselves. This had became a considerable problem especially when the first electric motors were set to service.

That is why there is a tendency to make all the modern railway vehicle drives sprung and to separate them from the source of vibrations as much as possible. One of the currently used drive type is shown on Fig. 5. It is a partialy suspended drive. Fully sprung electric motor is placed on the bogie frame and gearbox is situated partially on bogie frame and partially on the wheelset axle.

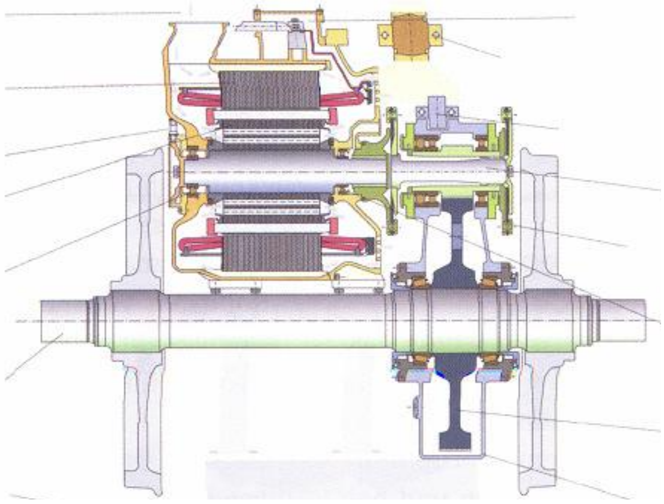

Fig. 5. *Partially sprung Vectron locomotive drive scheme [10]*

This kind of drive seems to have one specific property. Thanks to the gearbox situated on the wheelset axle the wheelset inertia center is translated transversaly out of the wheelset center. This translation caueses the wheelset to oscillate around this translated point and makes relative slips on both wheels diferent. That means there can be different slip inclination on both wheels. Current research running collaterally with this work is targeted on how much this assymetry can affect the slip inclination and what the consequences can be.

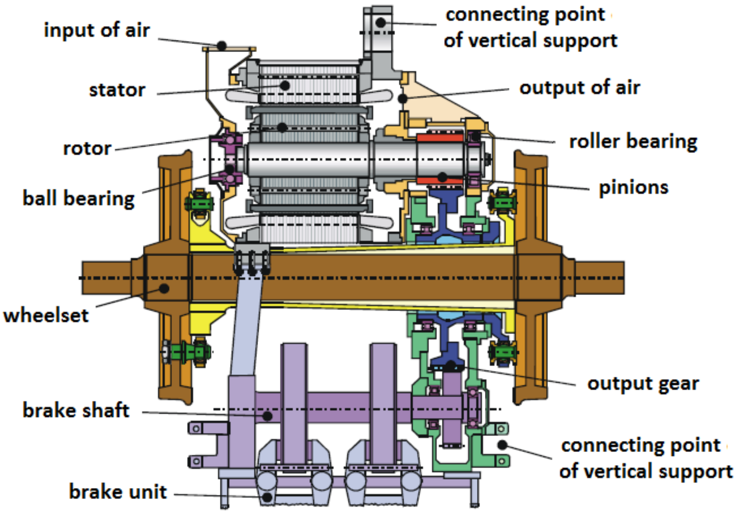

Fig. 6. *Fully sprung Taurus locomotive drive scheme [10]*

The most modern railway vehicles use fully sprung drive. It is based on the use of the hollow shaft surrounding the wheelset axle. This shaft serves as a cardan shaft and allows the motor and the gearbox to bu fully suspended. Thanks to that the drive is protected against vibrations.

2.3 Drive regulation

When the limit of adhesion is exceeded, the wheel starts to slip freely. This causes the wear of wheel and rail and it is initial vibration impuls. This is the reason why intervention must be done. Motor torque is then decreased and this allows the wheel to re-establish the adhesion. It means return the operating point from unstable part of characteristics (red line) back to the stable part of characteristic (green line) as seen on Fig. 7.

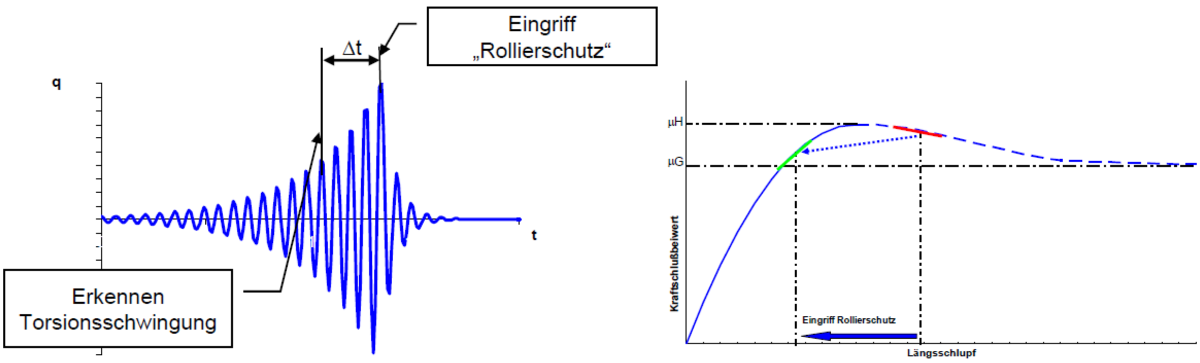

Fig. 7. *Operating point movement from unstable part back to the stable part leading to re-establishing adhesion and dumping wheelset axle oscillations during Δt time [4]*

This is why drive the regulation needs to be used. It can solve problems but also create other problems when the drive regulations often tries to re-establish adhesion and keep the torque on high level. This can produce other torsion oscillations.

2.4 The approaches of solving dynamic problems

While complex mechanical systems are solved there is a tendency to make it as simple as possible because of high hardware requirements and results clarity. This approach was used in researches of Doc. Lata or Ing. Zeman. Both of them used some limitations on their calculation models. For example on the drive itself (see Fig. 8.) [3], or on the bogie itself (see Fig. 9.) [7].

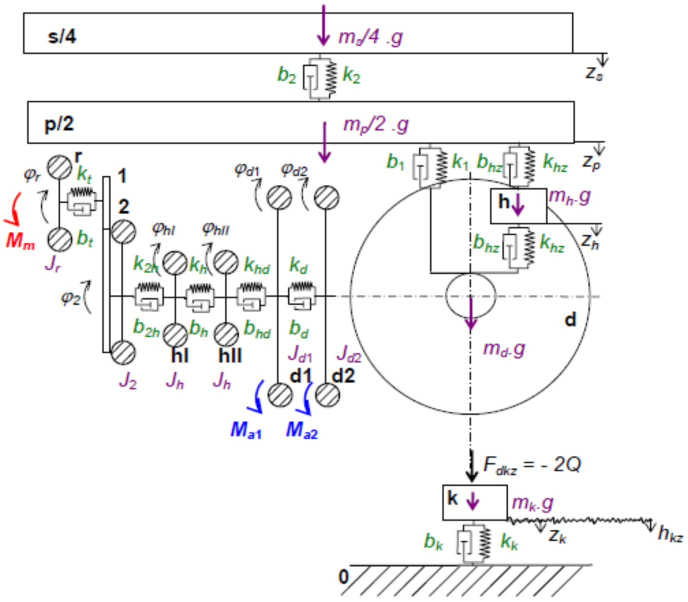

Fig. 8. *Calculation model dealing only with torsional drive system. The wheelset is loaded just with verticaly affecting mass representing a half of the bogie mass and a quarter of the vehicle body mass. [3]*

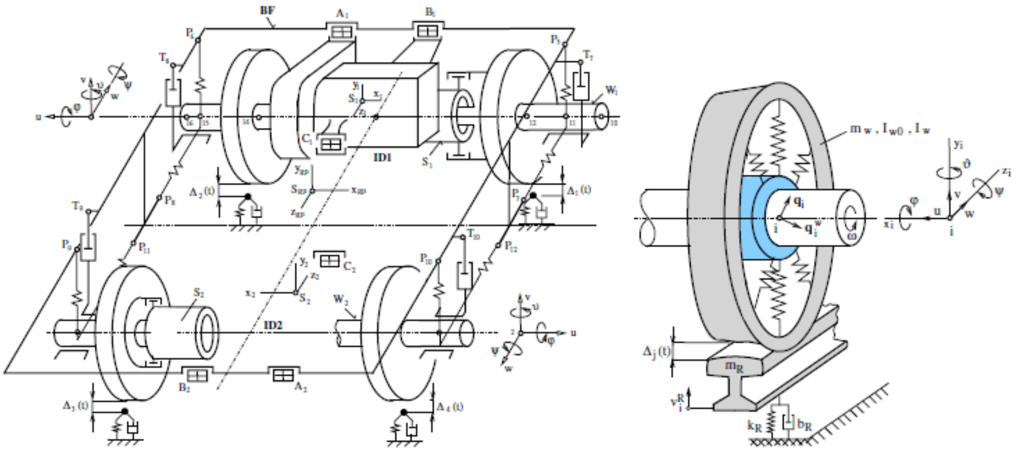

Fig. 9. *Calculation model dealing only with drive bogie without torsional stiffnesses. Vehicle body is substitued with a verticaly affecting mass representing a half of the vehicle body mass. [7]*

3. Simulation model

The tendency to make it simple can lead to neglecting of important influences on vehicle and its drive dynamic. This is the reason why there is a tendency to create more complex vehicle model – modern locomotive. So there is a need of creating a model dealing with standard mechanical expressions (vertical oscillations, rolling...) and also dynamic of the drive itself (torsion system).

3.1 Model creation

Within these requirements a model of three-system modern locomotive with fully sprung drive has been created in SIMPACK MBS[1] software. Collaterally with this a purely analytic model has been created for comparsion of recently used drive designs.

Basic parts of this model are two torsionaly flexible axles wheelsets. They are concieved as torsional springs connecting both wheels with respect to the used software.

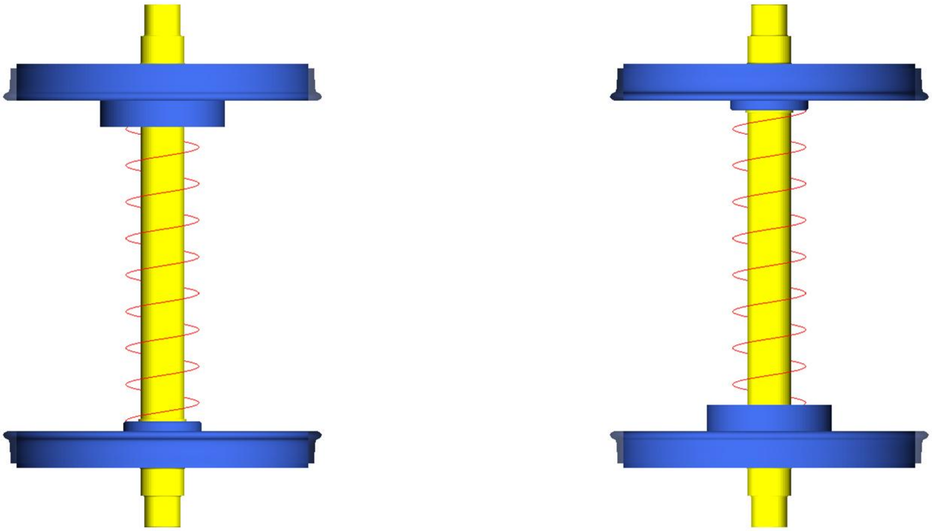

Fig. 10. *A pair of torsionally flexible wheelsets*

Each wheelset has it own drive unit containing motor, gearbox and a hollow shaft. Every shaft as well as the axles are torsionally flexible.

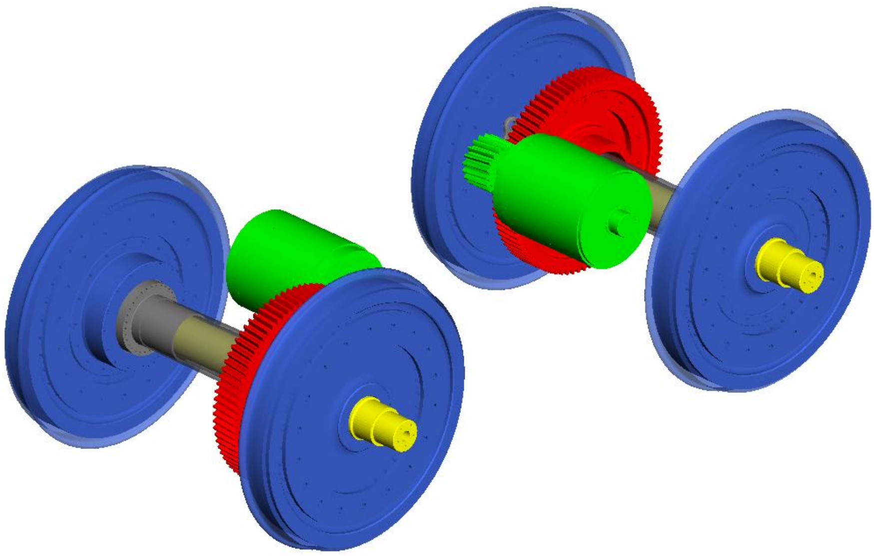

Fig. 11. *Wheelsets with drives*

[1] MBS – Multibody simulation. Type of a numerical simulation where the rigid bodies with force elements and constrainsts are used.

Both wheelsets and their drives are bound to one system via bogie frame and other carry structures.

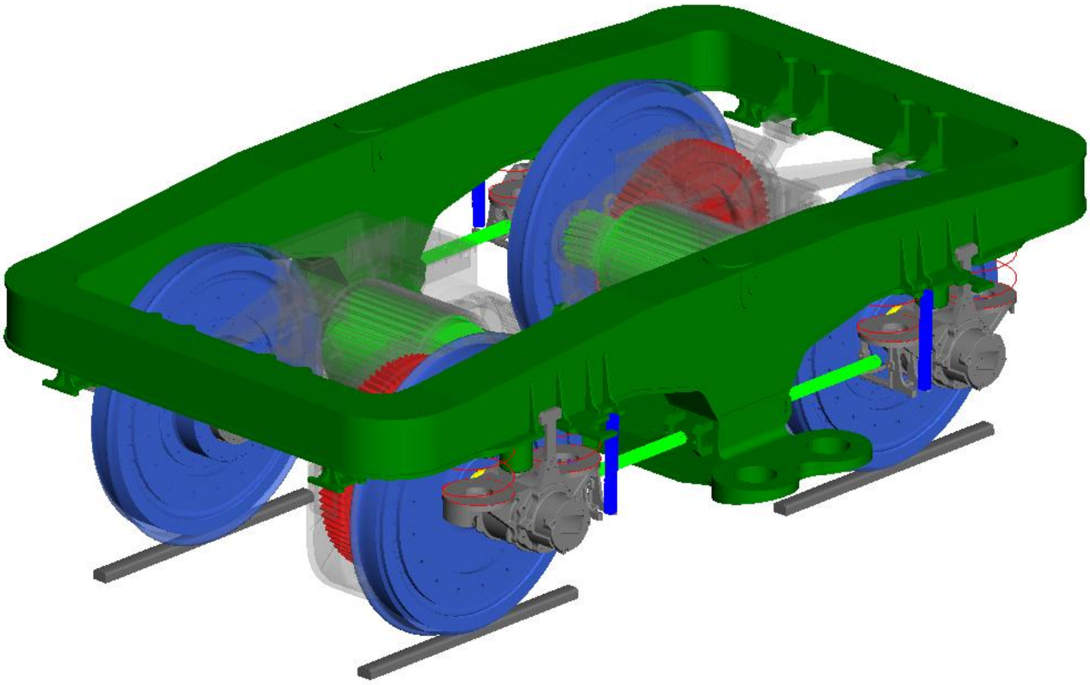

Fig. 12. *Locomotive drive bogie*

On the two of these bogies is placed vehicle body.

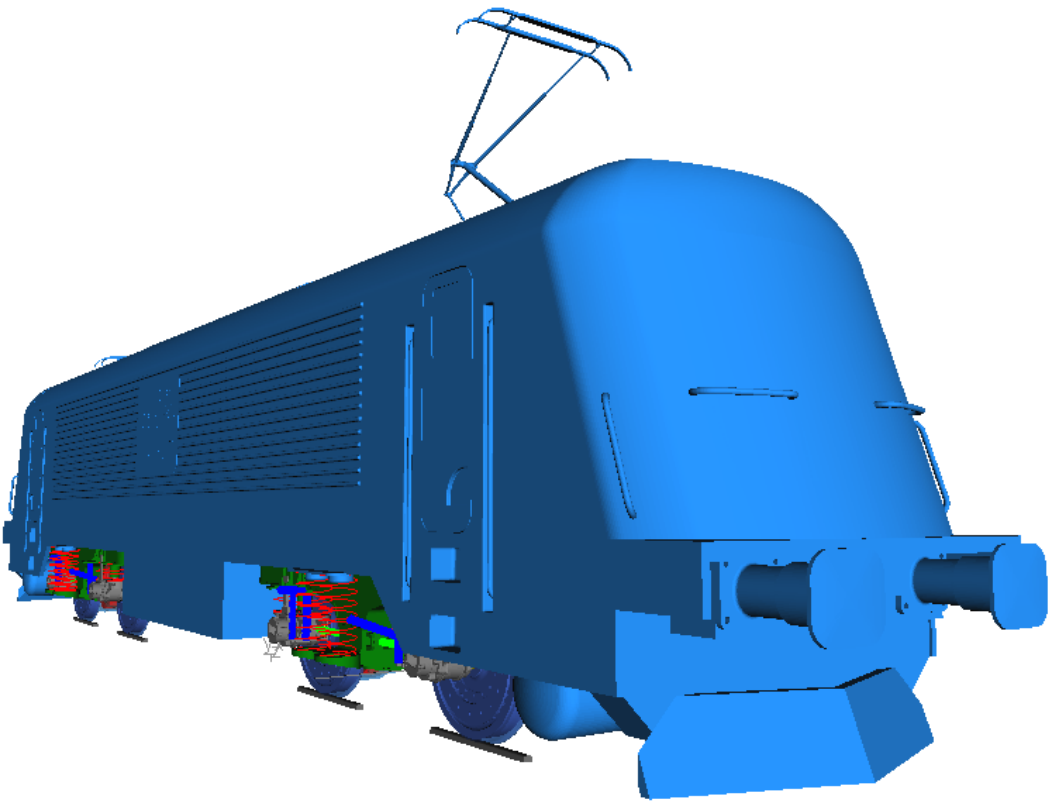

Fig. 13. *Complete locomotive model*

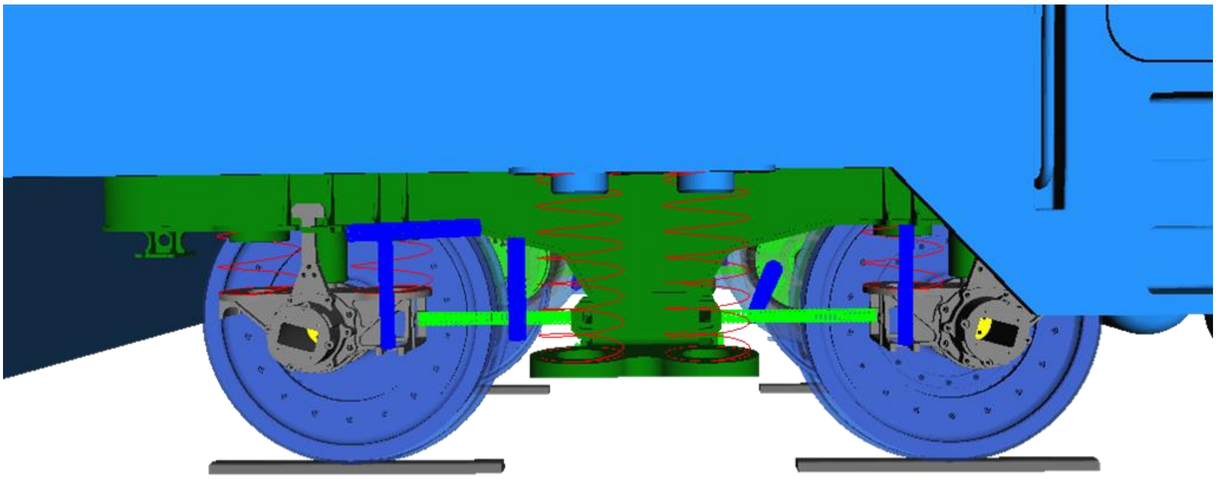

Fig. 14. Body & bogie connection detail

The model considers mechanical system and its superior electronic control system. This allows to include anti slip protection influence which could lead to additional torsional oscillations appearance.

Electronical part is solved via SIMULINK software working in cooperation on used MBS software. Basic scheme is presented on Fig. 15.

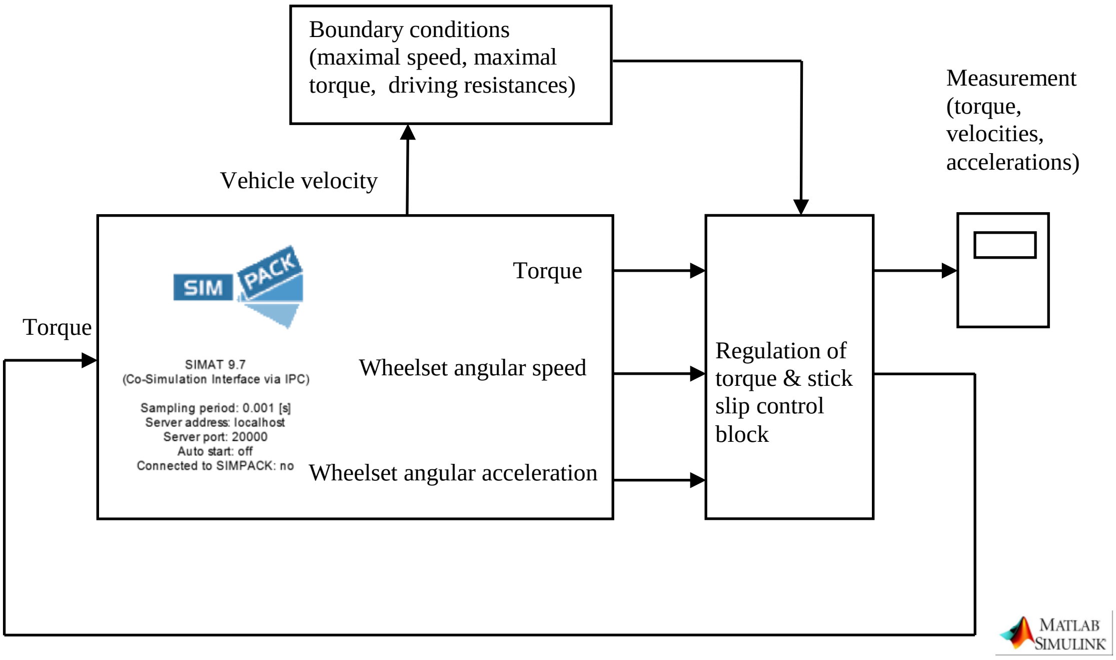

Fig. 15. Locomotive drive reagulation scheme

The basic part of the structure is a feedback control ciruit. The SIMAT block solves mechanical values of the system for example revolves, accelerations e.g. It also gives the actual torque value. The SIMAT block output then continues into the regulation block. According to the boundary conditions of the model there is a resolution made if the wheelset is in state of rolling or slipping and if there is a need to increase or decrease the torque value.

3.2 Future plans

The model will be tested within possible drive conditions leading to torsional oscillations. It means a straight track drive and a small radius curvature drive with different adhesion conditions. There is a tendency to create conditions similiar as much as possible to real scenario when a vehicle drives near the limit of adhesion as seen on Fig. 16. The area of interest is a part of characteristics where tractive effort mingles with its adhesion limit or is restricted by adhesions of the Curtius & Knifflers teoretical adhesion limit. [1]

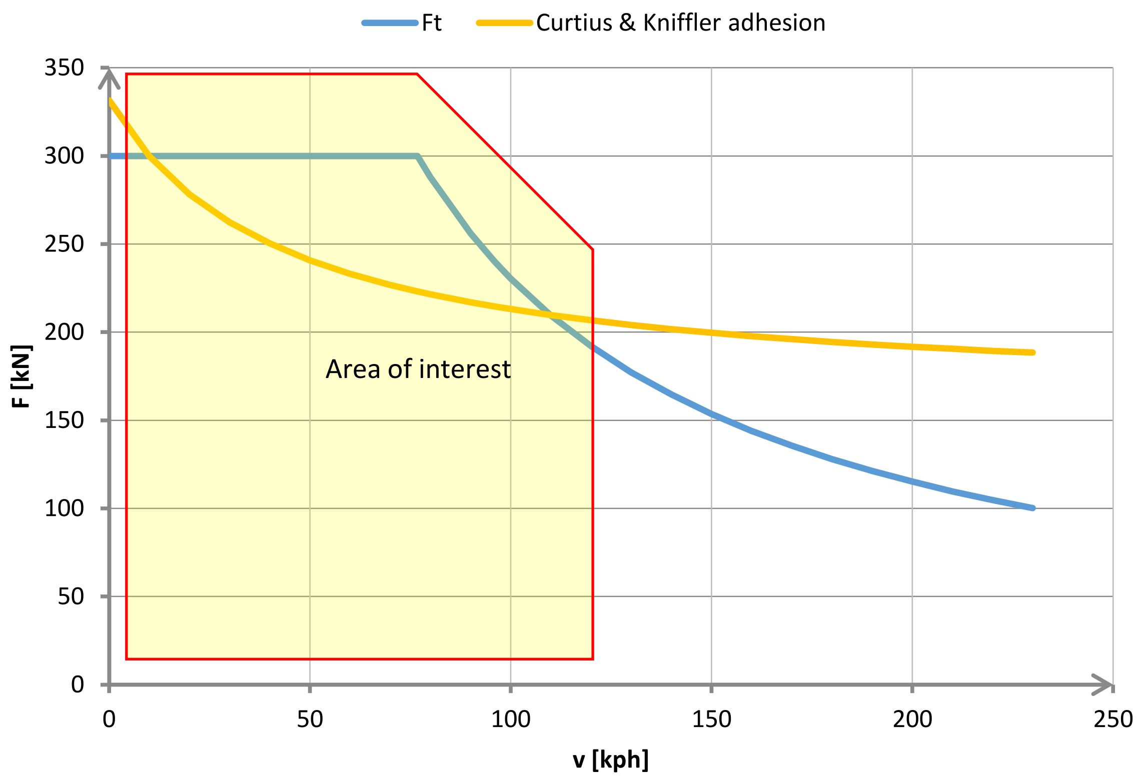

Fig. 16. *Traction characteristics for a locomotive with power 6,4 MW*

For simulation purposes there are two tracks considered:

- straight track; low geometrical quality of the track; friction coefficient 0,15÷0,4
- radius R250 m curvature; building elevation of 0÷150 mm; low geometrical quality of the track; friction coefficient 0,15÷0,4

There is also driving resistance considered and force on the coupler representing the real train load.

3.3 Measured values

The main objective of research is torsion tension value in the axles. According to the used MBS software this value will be measured on the basis of relative wheel rotation. This will be subsequently recalculated into the axle torque according to the equation (1).

$$M_t = k_t \cdot \varphi \tag{1}$$

4. Work objectives

The objective of the presented work is to compare torque values which can occur in the model and on real vehicles. Then according to this to determine if the torque values can be harmful to wheelset axles or press fitted joints with cooperation of torsion oscillations.

5. Summary

Within the first grad study the critical research targeted on railway vehicle drives and their dynamic (especially torsion oscillations – in german Rolliermoment) has been elaborated.

Within SGS grant nr. SGS14/184/OHK2/3T/12 MBS simulation model has been created via SIMPACK and SIMULINK softwares. It will be used during following studies for testing within the change of main parametres (adhesion, speed of antislip protection reaction).

The target of this work is to find main sources of limit conditons when high torsion oscillations amplitudes may occur. Another objective is to find the solution erasing or at least reducing its consequences on drives components.

List of used symbols

b	dumping constant	$(kN \cdot s \cdot m^{-1})$
F	force	(kN)
f_x	x-axle friction coefficient	(1)
k	stiffness	$(kN \cdot m^{-1})$
k_t	torsional stiffness	$(kNm \cdot rad^{-1})$
m	weight	(kg)
M_t	torsion moment	(kNm)
s_x	x-axle relative slip	(1)
v	velocity	(kph)
φ	angular turn	(rad)

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