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SIMULATION OF INFLUENCE OF TRANSVERSE WHEEL-SET MOVEMENT ON TORSION OSCILLATIONS

SIMULACE VLIVU PŘÍČNÉHO POHYBU DVOJKOLÍ NA TORZNÍ KMITÁNÍ

Abstract

With increasing importance of the railway transport the demands on economic and functional features of the railway traffic increase as well. The features are influenced by many factors, whose identification, direct measuring and impact detection are not easy to obtain in the real service. A computational simulation and a roller rig are suitable means, which enable to recognize an amount of physical limitation influences in conjunction with proposed vehicle construction and with supposed surrounding service conditions make everything clear before a vehicle commissioning. Therefore, the Simulink model, focused on the field of research of traction wheel-sets torsion dynamics and an influence of adhesion conditions, was built, has been used and developed within SGS (Student Grant Competition) and PhD study programs. In the past, the model served for investigation of torsion oscillation excited by changes in torque transfer. In this paper we focus on another source of asynchronous peripheral speed of wheels of a wheel-set. It is given by railway vehicle wheel conicity. It will be shown, how the contact circle diameter change influences the torsion load of the wheel-set axle and the load type.

Abstrakt

S rostoucím významem kolejové dopravy rostou také nároky na ekonomiku a funkčnost jejího provozu. Ty jsou ovlivňovány řadou faktorů, jejichž identifikace, přímé zjišťování a dopad je v reálném provozu velmi obtížné měřit nebo dlouhodobě sledovat. Počítačová simulace a kladkový stav jsou vhodnými prostředky, kterými lze rozpoznat míru vlivu fyzikálních omezení ve spojení s navrhovanou konstrukcí vozidla a s předpokládanými okolními podmínkami provozu vše vyjasnit před uvedením vozidla do vlastního provozu. Proto byl v rámci SGS (studentská grantová soutěž) a doktorských studijních programů sestaven, používán a rozvíjen model v Simulinku zaměřený na oblast výzkumu torzní dynamiky hnaných náprav a vlivu adhezních podmínek. V minulosti sloužil ke zkoumání torzního kmitání buzeného změnami přenosu krouticího momentu. V tomto článku se zaměřujeme na jiný zdroj asynchronní obvodovou rychlost kol dvojkolí. To je dáno kuželovitostí kol kolejových vozidel. Bude ukázáno, jak změna průměru kontaktní kružnice ovlivňuje torzní zatížení osy dvojkolí a druh zatížení.

Keywords

Wheel-set, wheel conicity, wheel-set kinematics, torsion moment, load type

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1 INTRODUCTION

From the perspective of transport engineering, importance of railway transport is significant Irrespective of its almost 200-year-old expansion given by its economic and ecologic impacts there are some new challenges that are to be solved. One of the most frequently used investigation methods is simulation, because experiments carried out on real vehicles in the phase of their development are not imaginable.

One of the research directions at Czech Technical University in Prague, Mechanical Engineering Faculty, we are reporting in the paper, is aimed at transition and electromechanical phenomena in traction drives of railway vehicles. We have proposed a simulation model based on the image of a railway vehicle that has been understood in a simplified way as an object of specific components as shown in Fig. 1.

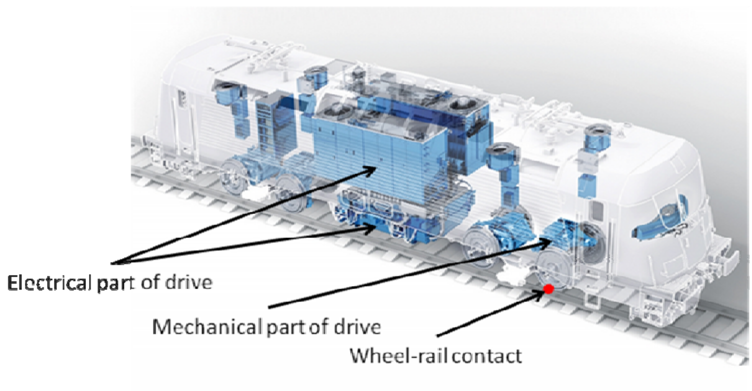

Fig. 1 Parts of a railway vehicle drive train [6]

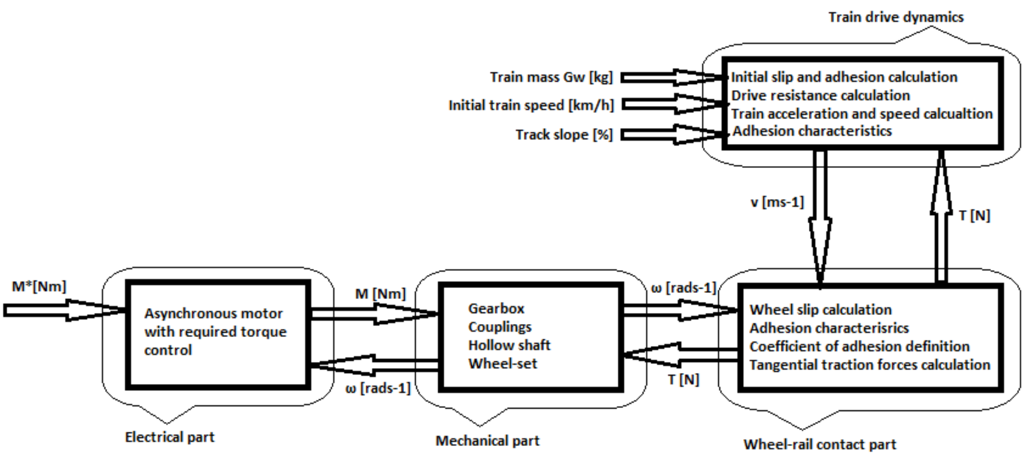

Fig. 2 Scheme of simulation model parts

Simulation model in MATLAB Simulink was built in a arrangement that is depicted via the scheme in Fig. 2 presenting basic blocks, their inputs and outputs and links among them (M^*, M, ω, v, T).

where:

M^* - adjustable torque [Nm],

M – generated torque [Nm],

ω – angular speed [rad/s],

v_S – vehicle velocity [m/s],

T – tractive force [N],

The simulation model we used is the latest version of continuous development with respect to specific needs of the research and effort to have more complex simulation tool. That is why the effort to implement the influence of wheel-set transverse movement and subsequent torsion load of the axle into simulations is one of the aspects. The interest to improve the model in this way was led by the fact, that there is a specific area of research in the railway engineering focused on the problematic of wheel-set overloading by torsion moments, externally acting forces, oscillations and their combinations. The effort of researchers in this area is about to have more safe and reliable vehicle due to restriction of acting load via predictive control as described in [1] or due to creation of simulation models to predict excessive loads for a vehicle design phase [2], [3], [4].

2 WHEEL-SET TRANSVERSE MOVEMENT

The wheel-set transverse movement is an oscillating movement typical for wheel-set with conical shape of the wheel thread. The wheel thread conicity became a typical feature for railway wheel-sets as it enables to drive a vehicle through curves with reduction of longitudinal slippage of wheels and therefore it reduces wear and tear of wheels and rails. Because of typical shape of the oscillation movement it has been called a sinusoidal movement as well. The principle description of these self-excited oscillations is explained in the text below. Already mentioned conicity of wheels thread is the essence of this wheel-set behavior, which is crucial for railway vehicle design for safety reasons and comfort behavior acting on passengers, who can personally feel it in case of a wrong suspension design. There are many principles and theories describing such a behavior. For example, Johanson's theory or Kalker's theory are more sophisticated as implementing forces acting in the wheel-rail contact caused by slippage and spin respectively and taking into account connection of wheel-sets in a bogie etc. In this phase the goal was to find out how significant impact has the wheel-set transverse movement within simulation results of the current simulation model. As the simulation model itself is not so sophisticated to enable implementation of any of the more sophisticated theories right now, the decision was made to use the basic wheel-set kinematics theory. The result of this theory is required transverse movement of a free wheel-set rolling on a straight track. Just the conicity in conjunction with the transverse movement causes change of the rolling circles diameters, see Fig. 3. And the effort is to detect the effect of different rolling diameters of the left and the right wheel on the axle torsion load.

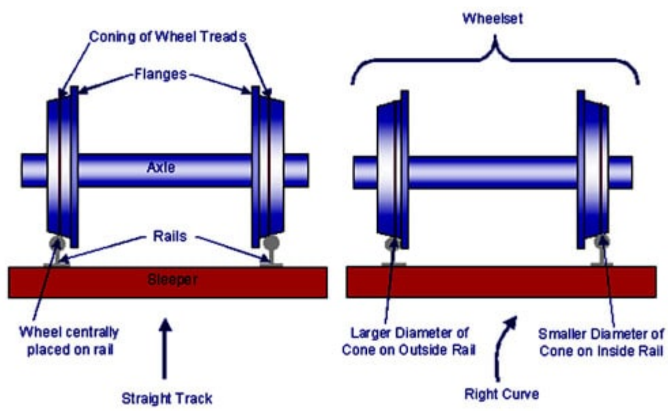

Fig. 3 Influence of transverse movement on rolling circles diameter [7].

2.1 Movement of a free wheel-set on a straight track

When a wheel-set rolls over a rail track there is a specific value of transverse gap 2σ between rails and flange of wheels, which enables that the wheel-set can take a general position on rails. This position is given by a transverse wheel-set's shift y and a rotation φ_Z around the vertical wheel-set axis. A simplified idea of such a situation can be depicted as a double-cone rolling over two lines, which are distant by a measure $2s$, see Fig. 4. $2s$ defines the nominal distance between rolling circles. The derived formulas of required transverse movement of a wheel-set $y(x)$ (7) and $y(t)$ (8) describes the sinusoidal behavior of the wheel-set in length domain and time domain respectively. Just the function $y(t)$ (8) is needed to calculate the continuous change of rolling circle radius $\Delta r_w(t)$, which cause the axle twisting and torsion load respectively.

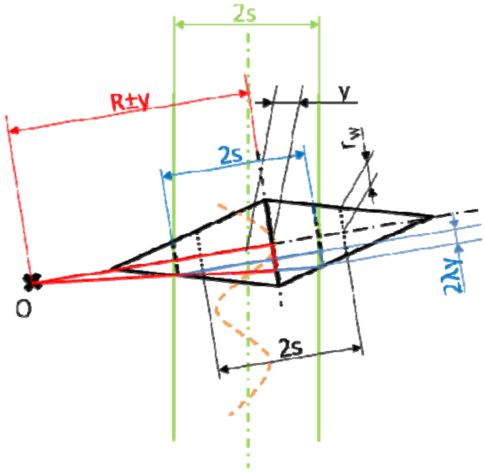

Fig. 4 Scheme of rolling double-cone

	$$\frac{r_W}{R+y} = \frac{2\lambda y}{2s}$$	(1)
	$$\frac{r_W}{R} = \frac{\lambda y}{s} \Rightarrow \frac{1}{R} = \frac{\lambda y}{r_W s}$$	(2)
	$$\frac{1}{\rho} = \pm \frac{y''}{\left(1+y'^2\right)^{3/2}}; y'^2 << 1$$	(3)
	$$\frac{1}{\rho} = -\frac{dy^2}{dx^2}$$	(4)
	$$\frac{\lambda y}{r_W s} = -y''$$	(5)
	$$y'' + \frac{\lambda}{r_W s} y = 0; \Omega_{DV} = \sqrt{\frac{\lambda}{r_W s}}$$	(6)
	$$y_{(x)} = y_0 \cos(\Omega_{DV} x) + \frac{\varphi_0}{\Omega_{DV}} \sin(\Omega_{DV} x)$$	(7)
	$$y_{(t)} = y_0 \cos(\omega_{DV} t) + \frac{v \varphi_0}{\omega_{DV}} \sin(\omega_{DV} t)$$	(8)

where:

r_w	nominal wheel radius [m]
R	radius of a wheel-set movement [m]
y	transverse wheel-set movement [m]
$2s$	nominal distance between rolling circles [m]
y_0	initial transverse wheel-set position [m]
x	driven distance [m]
t	time [s]
v	vehicle speed [ms^{-1}
λ	wheel thread conicity [-]
ρ	radius of general curve [m]
Ω_{DV}	angular frequency of a wheel-set transverse movement in a distance domain [m^{-1}]
φ_0	initial angle of a wheel-set rotation [rad]
ω_{dv}	angular frequency of a wheel-set transverse movement in a time domain [s^{-1}]

2.2 Rolling circle radius change

The rolling circle radius change (9) is given by current position of the wheel-set on rails and by the conicity of wheels. This quantity influences current value of rolling circle diameter and subsequently a wheel slip and a wheel torque. Via parameters of slip and torque the $\Delta r_w(t)$ function was implemented into the simulation model as presented by the scheme in Fig. 5.

$$\Delta r_{W(t)} = y_{(t)}\lambda \tag{9}$$

$$r_{W(t)} = r_{w,const} + \Delta r_{W(t)} \tag{10}$$

$$s_{(t)} = \frac{r_{W(t)}\omega_{W(t)} - v_{(t)}}{v_{(t)}} \tag{11}$$

$$M_{(t)} = T_{(t)} r_{w(t)} \tag{12}$$

where:

$\Delta r_w(t)$	rolling circle radius change [m]
$y(t)$	transverse wheel-set movement [m]
$r_w(t)$	current value of rolling circle diameter [m]
$r_{w,const}$	constant value of rolling circle diameter [m]
$s(t)$	wheel slip [-]
$v(t)$	vehicle speed [ms^{-1}]
$M(t)$	wheel torque [Nm]
$T(t)$	tractive force [N]
λ	wheel thread conicity [-]
$\omega_w(t)$	angular speed of a wheel [s^{-1}]

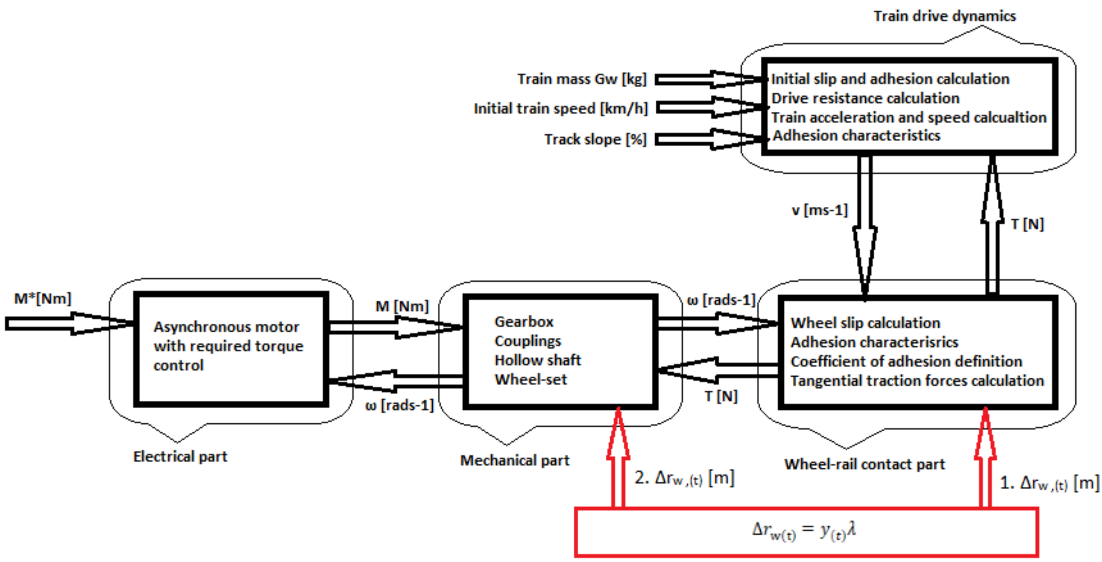

Fig. 5 Implementation of *$\Delta r_w(t)$* function into the simulation model

3 SIMULATION RESULTS

The intention was to obtain the knowledge how significant impact the transverse movement have on simulation results of the current model when we apply the simplest principle describing self-excited wheel-set oscillations. The simulation with implemented influence of sinusoidal movement of wheel-set verifying the effort is described below. It is a short drive cycle, which consists of two parts – the acceleration up to the speed of vehicle approximately 52 km/h and a drive with the constant speed of app. 52 km/h as depicted in Fig. 6**Chyba! Nenalezen zdroj odkazů.**.

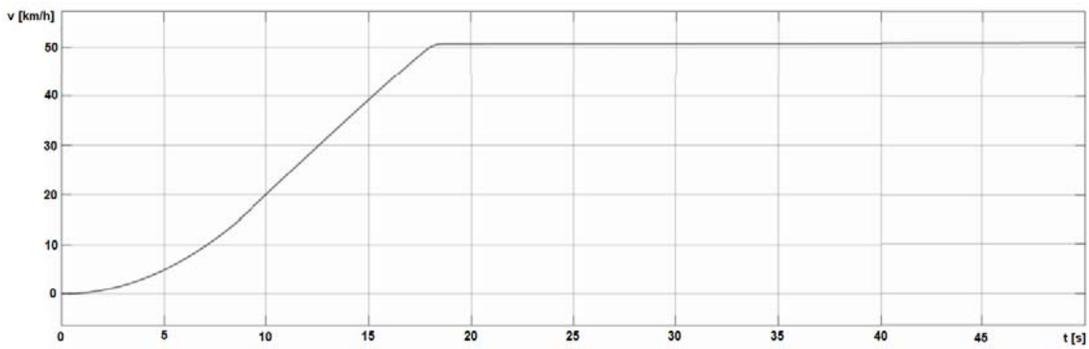

Fig. 6 Drive cycle

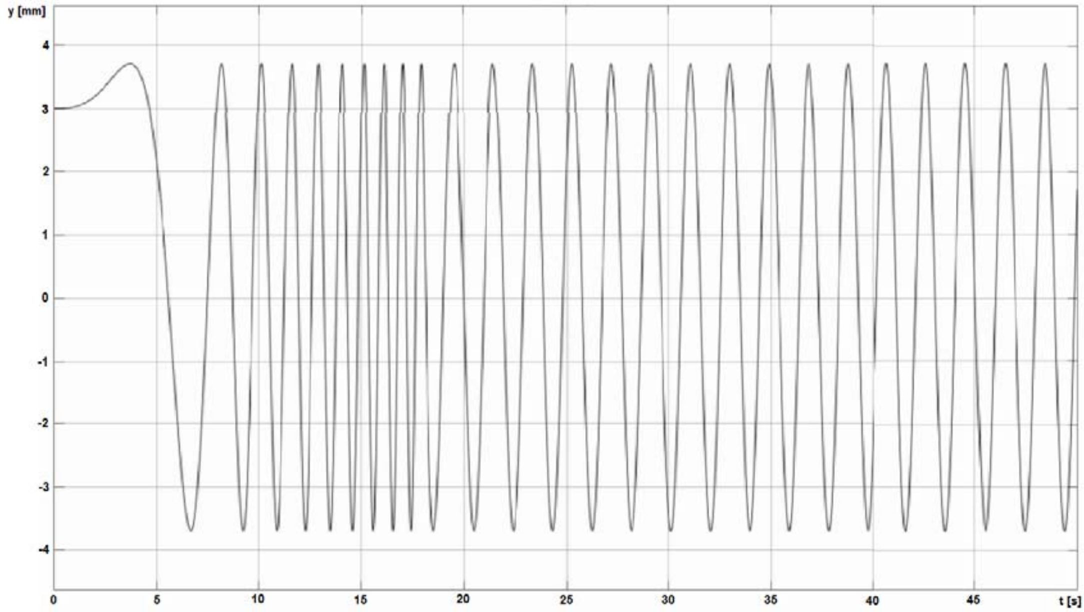

Fig. 7 Wheel-set transverse movement in time domain

The transverse movement simulations were carried out with specific initial conditions. Fig. 7 presents simulation example with initial condition of – $y(0) = y_0 = 3$mm and $y'_0 = \varphi_0 = 0{,}0005\ s^{-1}$. The impact of the transverse wheel-set movement and related continuous change of rolling circles radius is obvious in Fig. 8.

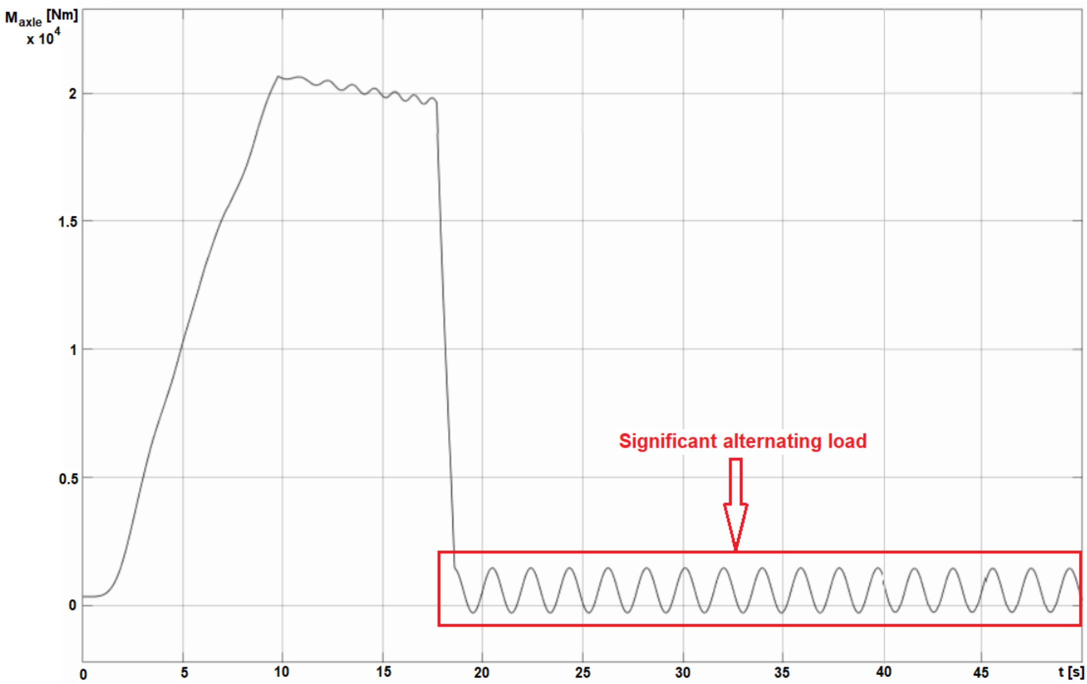

Fig. 8 Axle torsion load caused by axle twisting

Different rolling radiuses of wheels caused axle twisting and subsequent torsion load of the axle. In the steady state was observed very significant course of the torsion load and its dependence on the amplitude of *y(t)* and $\Delta r_w(t)$ respectively**Chyba! Nenalezen zdroj odkazů.**. The observed accrual of the torsion load amplitude as a function of the amplitude of *y(t)* presented in Fig. 9 is such a significant that it changes the type of the axle load – from the pulsating to the alternating load type for low speeds with low nominal torque.

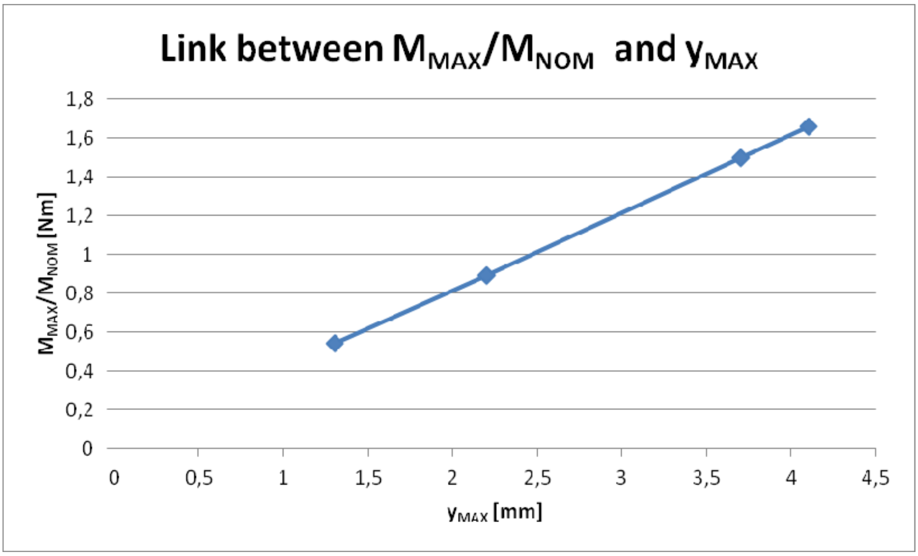

Fig. 9 Axle torsion load amplitude vs. wheel-set transverse movement amplitude

A typical characteristic of the sinusoidal wheel-set movement, which is a self-excited oscillation in principle, is a frequency of this oscillation. The frequency is a function of the wheel-set geometry and speed of the vehicle as stated by formula (13) below.

$$f_{DV} = \frac{\Omega_{DV} v_{(t)}}{2\pi} \tag{13}$$

where:

f_{DV} frequency of a wheel-set transverse movement [s^{-1}]

Ω_{DV} angular frequency of a wheel-set transverse in a distance domain [m^{-1}]

v(t) vehicle speed [ms^{-1}]

In our case the geometrical parameters are $\lambda = 1/40 = 0{,}025$; $r_w = 0{,}625$ m; $2s = 1{,}5$ m; $v = 14{,}84$ ms^{-1}. For these parameters the calculated frequency $f_{DV} = 0{,}545$ Hz, which is in an agreement with the frequency analysis of the axle torque signal in Fig. 10.

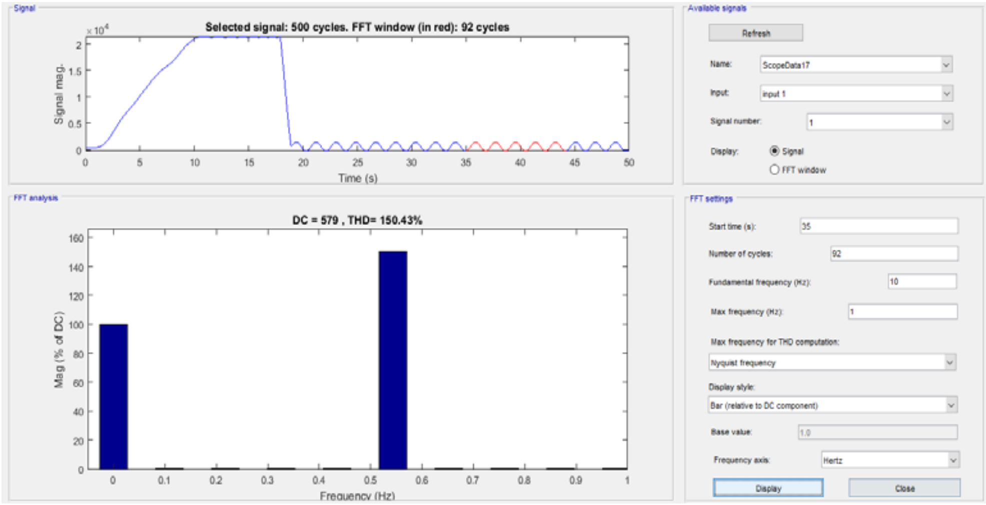

Fig. 10 Frequency analysis of the axle torque

4 CONCLUSIONS

The effort to improve the simulation model by implementation of the wheel-set transverse movement based on the simplest theory describing self-excited sinusoidal movement of a free wheel-set on a straight track led to obtain the following knowledge The simulation results proved, that the behaviour of the wheel-set with conical wheel's thread causes significant axle twisting as a result of different wheel's rolling radiuses. The axle twisting means a significant torsion load of the axle as well. Just the effect of the excessive axle torsion load is what has been researched to find more precise methods to design safer and more reliable wheel-sets. The second conclusion which was made with respect to the observed simulation results is as follows. For low service speeds with low traction torques the axle torsion load can even change its type with increasing amplitude of the transverse wheel-set movement. The simulations showed that the load type changes from the pulsating to the alternating load type.

5 ACKNOWLEDGEMENTS

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