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Personal rapid transit vehicle with polyurethane wheels – modelling and simulation issues

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Abstract

The article focuses special attention to the dynamic response of wheels – track interaction in Personal Rapid Transit (PRT) vehicle's application. The main issue is the wheels/ track contact model for polyurethane treaded wheels. The contact model has been defined using the available UA-Tire analytical model (University of Arizona Tire Model) initially worked out in the paper [1], The model is available in ADAMS simulation environment. To obtain the necessary parameters a simulation model in FEM environment as well as the polyurethane treaded wheels have been constructed. The model has undergone quasistatic load tests in order to find indispensable characteristics. The paper includes the description of simulation model of the PRT vehicle and presents selected outcomes of kinematic and dynamic analyses.

1. Introduction

Dynamic interaction between a wheel and track is crucial for determining the dynamic behaviour of PRT vehicle. It is more complicated in modern PRT vehicles because of using wheels with polyurethane tread. The main issue is a limited amount and availability of the experimental data for the model of wheel- track contact. Thus, the model of the contact needs to take into account difficulties in obtaining essential experimental data, e.g. for advanced models such as Magic Formula tyre model. In this paper, due to lack of experimental data, a simulation model has been constructed in FEM environment in order to perform tests to obtain data which will substitute the essential experimental data. Moreover, the contact model should be described with relatively small number of parameters.

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Literature review, including [2] shows that only Fiala and UA-Tire models require basic physical data of the tire whereas the remaining models require appropriate data obtained through experimental tests and measures. It is also known from available papers published that UA-Tire model is successfully utilized for simulation of the vehicles with non standard tires. As an example, go-cart simulation model in Adams environment [3] or multirole military vehicle [4] can be taken.

In order to determine the parameters of the presented wheel model (par.2.2) with polyurethane tread, FEM model was developed with the purpose of providing required data for contact modelling. Data (contact model parameters) were obtained during several simulations reflecting real tire tests. FEM results substitute experimental data. For polyurethane tread as the most important part of the model, a hyperelastic material was applied. Material was described by Mooney-Rivlin (5-parameter) model. Validation of the FEA wheel model against the data available from the references, i.a. [5] was also conducted. Furthermore, the model was tested in order to obtain the characteristics crucial for further dynamic analyses.

2. Description of the contact parameters

The requirements and CAD 3D model of the wheel for wheel/rail model contact were created. Next, FEM model was developed with tests, validation and selected characteristics determination.

Obtained characteristics provided UA-Tire model required parameters. Tire model was tested in MBS (Adams/View) in terms of contact model stability. Determined coefficients are presented in par. 2.3 and 2.4.

2.1. Assumptions

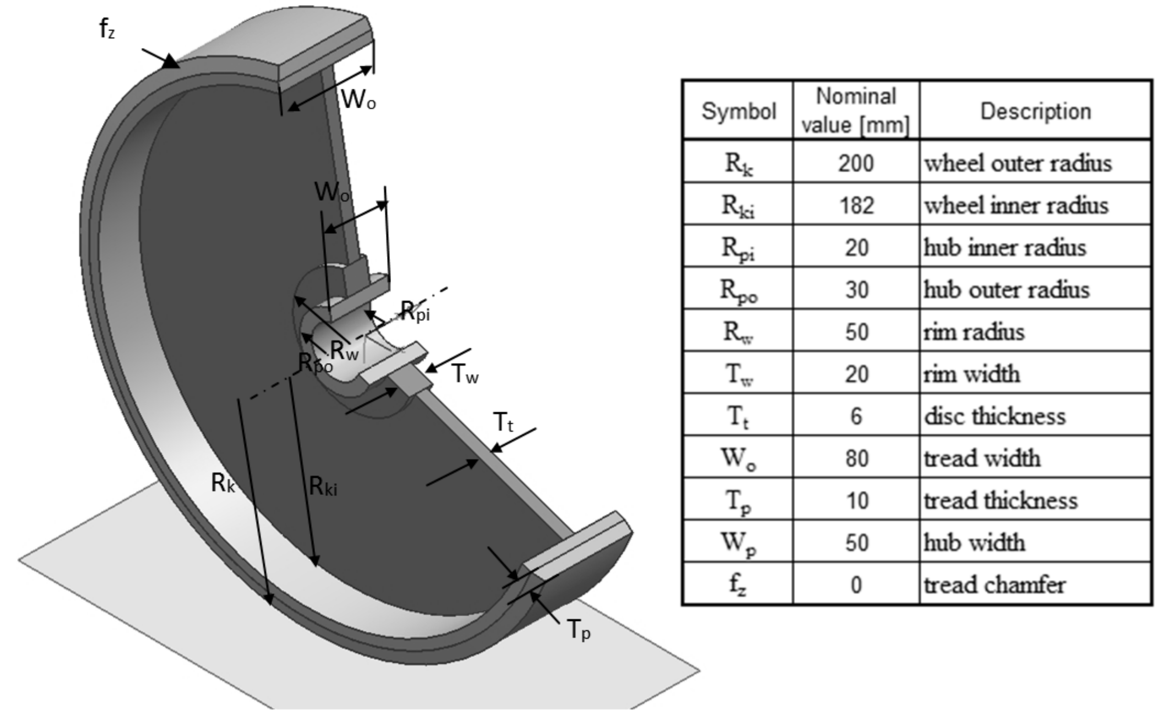
The use of linear motor LIM as a drive, requires to maintain a small wheel deflection during motion. Such condition is met by the use of wheel with polyurethane tread usually below 20 mm thickness.

The type of wheel mentioned requires contact model cable of:

1. describing the wheel specific structure
2. appropriately reflect the motion on smooth surfaces, like special PRT track
3. using user-defined function of wheel deflection due to load (deflection_load_curve),
4. replicate precisely enough the wheel self-aligning torque distribution because of the special in-track guidance system application.

2.2. CAD 3D model of the wheel parameters

The structure of the wheel was simplified. The wheel consists of smooth steel disc connecting hub and thin polyurethane treaded rim. Nominal geometry CAD model with key parameters is presented in Figure 1.



Symbol	Nominal value [mm]	Description
R_k	200	wheel outer radius
R_{ki}	182	wheel inner radius
R_{pi}	20	hub inner radius
R_{po}	30	hub outer radius
R_w	50	rim radius
T_w	20	rim width
T_t	6	disc thickness
W_o	80	tread width
T_p	10	tread thickness
W_p	50	hub width
f_z	0	tread chamfer

Fig. 1. Nominal wheel CAD model with geometric parameters

2.3. Tire model parameters

In the UA-Tire model, inputs described in Table 3 are the functions of kinematic quantities from the Table 2. The summary of UA-Tire.model physical parameters is presented in the Table 1.

Tab. 1

Input parameters of UA-Tire model

Id.	Name:	Symbol	Unit
1	*Tire unloaded radius*	r_l	***m***
2	*Vertical stiffness*	k_z	***N/m***
3	*Vertical damping*	c_z	***N s/m***
4	*Rolling resistance parameter*	C_r	***m***
5	*Longitudinal slip stiffness, curve slope* $\partial F_x/\partial\ \kappa$ *for* $\kappa = 0$	C_S	***N***
6	*Cornering stiffness, curve slope* $\partial F_y/\partial\alpha$ *for* $\alpha=0$	C_α	***N/rad***
7	*Camber stiffnes, curve slope* $\partial F_y/\partial\gamma$ *dla* $\gamma=0$	C_γ	***N/rad***
8	*Static friction coefficient*	U_{min}	-
9	*Dynamic friction coefficient (with developed slip)*	U_{max}	-

Tab. 2

Input variables of UA-Tire model

Id.	**Name:**	**Symbol**	**Unit**
1	*Longitudinal slip*	κ	-
2	*Lateral slip as slip angle*	α	***rad***
3	*Inclination angle*	γ	***rad***
4	*Wheel deflection*	ρ	***m***
5	*Wheel deflection velocity*	$\dot{\rho}$	***m/s***

Tab. 3

Outputs of UA-Tire model

Id.	**Name:**	**Symbol**	**Unit**
1	*Longitudinal force*	F_x	***N***
2	*Lateral force*	F_y	***N***
3	*Normal force*	F_z	***N***
4	*Rolling resistance moment*	M_y	***Nm***
5	*Self-alinging torque*	M_z	***Nm***

Forces and momentums definitions are provided in [1], [6] and [7].

2.4. Parameters determination

Described CAD model (par. 2.2) was used for FEM model creation with two types of elements:

- solid, as a wheel structure, including tread
- contact, to describe wheel and ground relative behaviour (contact pairs)

Developed model may be utilized for several static and dynamic analyses. As a result, data directly connected with the structure stiffness (deflections, stresses), reactions or responses to dynamic excitations may be evaluated. This paper is focused on demonstration of the fundamental characteristics required for MBS systems contact modelling process.

Coordinate system of simulation model is common with SAE tyre axis system. The beginning of this coordinate system is located in the center of wheel- ground contact area, and geometrical interpretation is presented in [8].

During static analyses, the following distributions were determined:

1. vertical stiffness, comes from deflection and vertical force (Fz) –(Fig.2)
2. lateral stiffness as a function of inclination angle γ and lateral force Fy
3. longitudinal stiffness as a function of longitudinal force Fx and slip s=(Rω-Vx)/Rω, where: ω- wheel angular velocity, Vx- wheel linear velocity, R- wheel dynamic radius
4. torsional stiffness, comes from momentum Mz and rotation angle along z axis

Using results presented in Fig. 2 the function of F(z)=1000z3+10000z2+100z was determined for Adams implementation. This function combines wheel deflection z as a result of acting vertical force F(z). Derived function presets good correlation to the measured points for deflection range from 0 to 0,5 mm which is the most sensitive for the simulation model. Moreover, for deflection of 0,5 mm the value of first derivative of F(z) was calculated yielding 1850 N/mm which is actually the value of vertical stiffness.

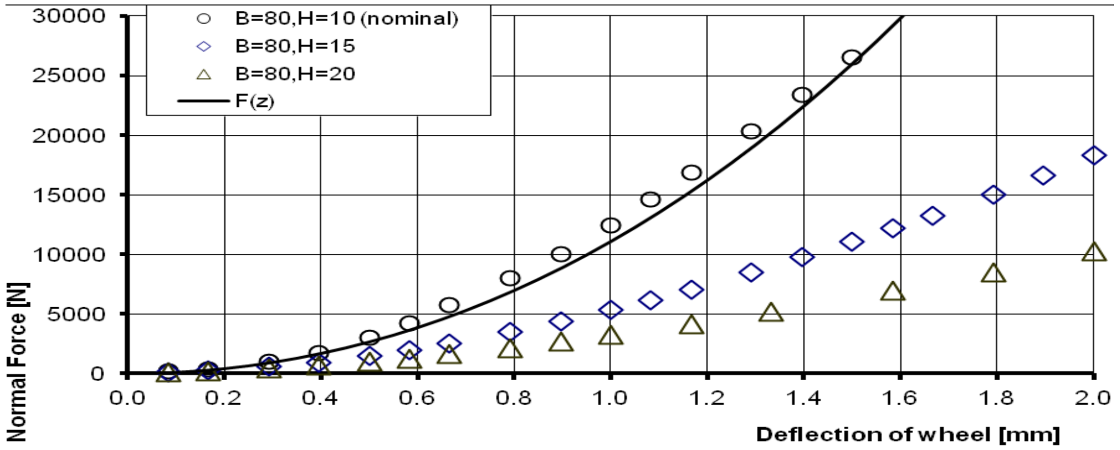


Fig. 2. Load deflection curve for some cases of parameters of PRT wheel

Remaining characteristics gave parameters which are listed in Table 1 as follow:

$$\left.\frac{\partial F_y}{\partial \gamma}\right|_{\gamma=0} = 200\frac{N}{deg} = \sim 12000\frac{N}{rad} \tag{1}$$

$$\left.\frac{\partial F_x}{\partial \kappa}\right|_{\kappa=0} = 150N \tag{2}$$

Where κ represents longitudinal slip.

$$\left.\frac{\partial F_y}{\partial \alpha}\right|_{\alpha=0} = 4\frac{N}{deg} = \sim 200\frac{N}{rad} \tag{3}$$

The values of friction coefficients (lines 8-9 in the Table 1) were assumed as 0,3 and 0,7. For vertical damping and the coefficient of rolling resistance the values of 50000 N*s/m and 0,001 m were taken respectively.

3. Description of the PRT bogie model

A PRT running on track is a complicated integrated system composed of several subsystems which are coupled to each other. The bogie is modelled based on the existing patents and present-day PRT systems reviews. Mechanical systems and construction features were investigated, analyzed and evaluated.

3.1. Bogie structure description

As a result, general structure of drive system was established and nominal simulation model defined and evaluated in ADAMS/View system. Model presented in this paper meets the conditions that reflect assumptions regarding PRT idea implementation.

The most important features:

- vehicle over the track /supported vehicle/
- two axles bogie with side control
- twisting axles system connected with stiff frame, possibility of small angles of twist
- frame mounted cabin in points via spring-damper elements
- drive-linear motor LIM/LSM
- in-track guidance system as side rollers sets
- linear motor located between axles and mounted to the frame, active part on board, passive one in the track

3.2. Multi-body description

A multi body (MBS) model of PRT bogie is described by 16 moving parts with 15 revolute joints. For the model, the total number of 21 degrees of freedom (DOF) is obtained. Fig. 3 shows a PRT bogie modelled with a commercial multi-body program.

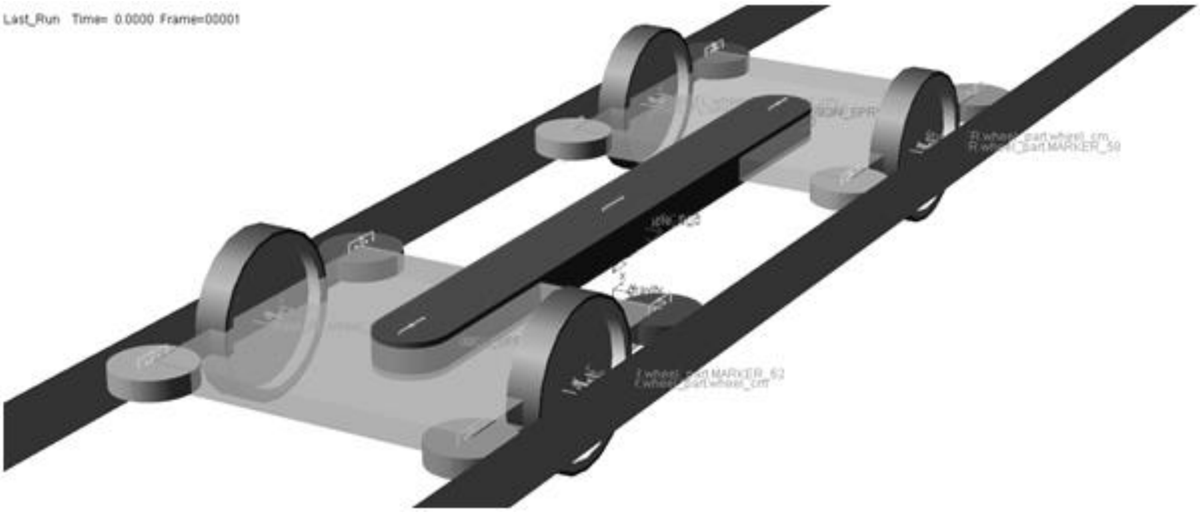


Fig. 3. The simulation model of the PRT bogie, (Adams View 2010)

Right-handed Cartesian coordinate system was assumed, where x axis aligns with a direction of the vehicle motion, z axis is oriented vertically down.

4. Verification of the contact model – simulation results

To verify the wheel/rail contact model a set of simulations have been performed. The selected results describe the motion with independently irregular rails. During simulation 2D Road type named „poly_line" was utilized. The profiles for the left and right track/rail are independent. This type of track model allows to reflect relative twist of a rail. Implementation of the mentioned excitation is presented in Fig. 4, where position of the centers of wheels axles, during motion, is shown. The values of twist angle for axles and wheels self-aligning torque for damped and undamped twist systems, are shown in Fig.5.

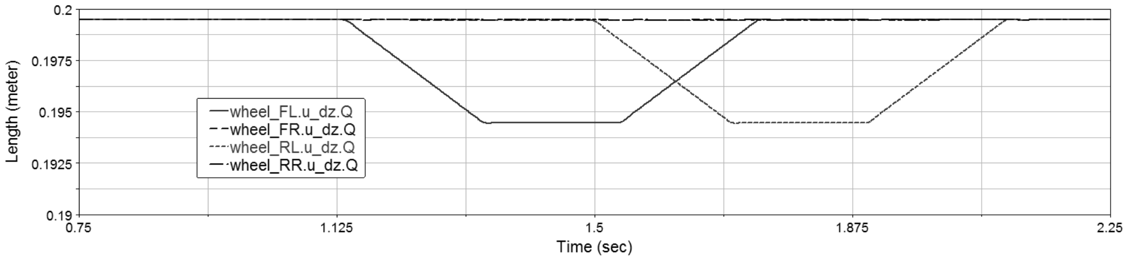


Fig. 4. Vertical (z direction) position of the center of wheels

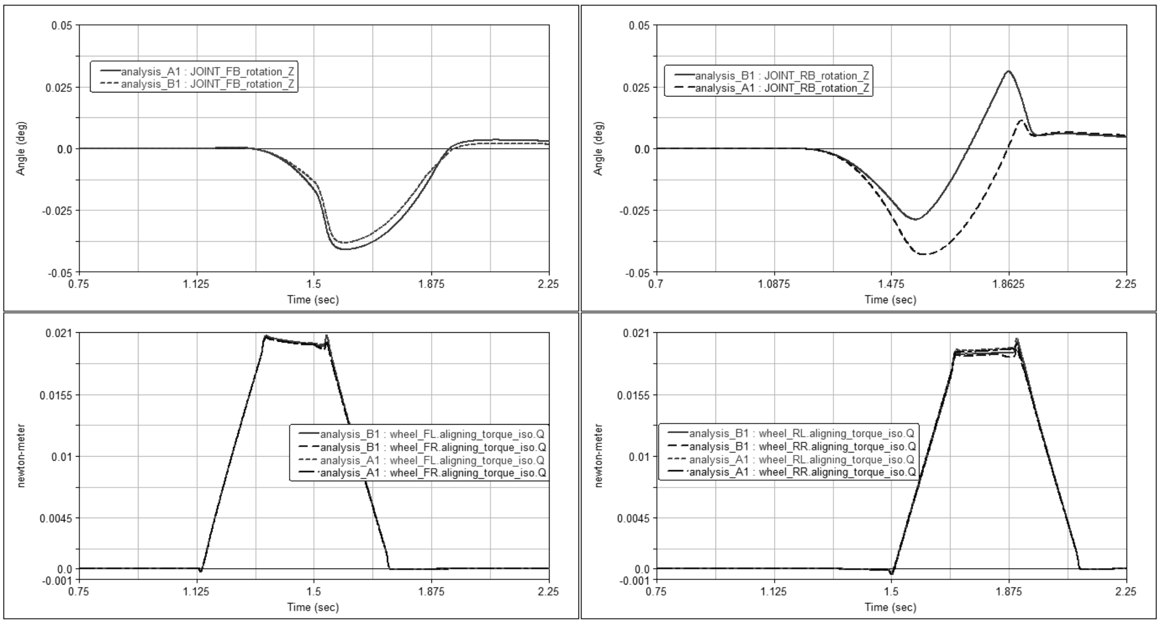


Fig. 5. The twist angle of the front axis (FB) and rear axis (RB) with the wheels self-aligning torque for damped (B1) and undamped (A1) twist systems of PRT vehicle

5. Summary

In this paper, the model of wheel/track contact for polyurethane treaded wheels has been studied by using the predefined UA-Tire contact model. The method, to obtain necessary contact parameters by using FEM analysis was proposed and a set of parameters for the presented 3D CAD model of the wheel, was listed. Moreover, the simulation results verify presented contact model. Preliminary results show that the model provides reasonable results.

In the future work the model, based on presented parameters will be validated through experimental test results on the laboratory test stand for PRT system [9].

Acknowledgement

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