DYNAMICS OF THE WHEELCHAIR AND WHEEL CONTACT

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Abstract. Nowadays on the one hand the requirements and prospects of wheelchair users in reference to comfort, usability, security and new possibilities of assistance are increasing. On the other hands, the economical general framework generates the need to reduce the development and production costs of wheelchairs. One resolution to this conflicting demands the usage of state of the art simulation tools in the area of dynamic co-simulation for vehicles. In this paper the modeling aspects and the results of the wheelchair dynamic behavior are presented. One important part for the dynamic behavior of wheelchairs is the tires and the road surface and the correct physical modeling of their parameters, consequently different tire models are used and discussed in this paper. The inputs of these models are normally the normal load, the sideslip angle and the longitudinal slip, and the outputs are shear force, aligning moment, and overturning moment. These models are implemented in simulation programs for multi body systems and the effect of the contact between the tires and the road were analyzed and compared for different combinations of these parts. With the proved models of the dynamical behavior in the next step it is possible to simulate different control systems to use in automatic or semi-automatic wheelchair. Also the influence of the wheelchair movements on the user and the implemented sensors can be analyzed in a more realistic way by using co-simulation possibilities. So the use of combined simulation models offer a effective tool for shorter design and testing time periods for new developments in the wheelchair area. The result of this work has extreme importance to the development of the new designs and parts for wheelchairs and for control system implemented in wheelchair.

Keywords: Wheelchair, dynamic, tire, behavior, simulation

1. INTRODUCTION

Recently, several intelligent wheelchairs have been proposed to meet the need in aging society. However most of the controls don’t consider the dynamic behavior of the tires. But especially the shear forces acting between the tires and the ground are important for the stability, the control and the handling of road vehicles.

According to Cabrera (2004), the dynamic behavior of vehicles is mainly influenced by the properties of tires. Thus, knowledge of the properties of the tire is required for proper development of a vehicle and an advanced control system. Consequently, the mathematical models of the tire are used to simulate the dynamic behavior of a vehicle. Because of the complexity, structural and mechanical nonlinearity of the tires, it is very difficult to establish a theoretical model that can accurately describe various mechanical properties of the tire under different conditions of operation.

Another advantage of dynamic modeling is to reduce the cost of developing new products, it is possible to implement and test them with the tools CAE (Computer-Aided Engineering) without the need of building a prototype. Thus the use of computational tools enables a reduction in the costs of development and more speed in developing new products. By Morency (2007), the design changes can be evaluated with a computer model in a fractional amount of the time it would take to construct, instrument, and test a physical prototype. The material and labor costs associated with computer models are usually much lower than the costs associated with physical testing.

2. CONTACT FORCES AND MOMENTS

For the analysis of the position and the trajectory it is necessary to use a orthogonal coordinate system, fixed on the ground and that usually coincides with the system axes fixed on the vehicle. The coordinate system used is shown in Fig.1. There are several forces, moments and angles that are very important in the behavior of the wheel. In general the two significant angles for tire models are the slip angle (\(\alpha\)) and the camber angle (\(\gamma\)). According to Gillespie (1992) the influence of the camber angle in the lateral force can be negligible, thus in this work was not considered this angle.

The longitudinal force (\(F_x\)) and overturning moment (\(M_x\)) are applied in the \(x\)- direction. The lateral force (\(F_y\)) and rolling resistance moment (\(M_y\)) are applied in the \(y\)- direction. The normal force (\(F_z\)) and the aligning moment or aligning torque (\(M_z\)) are applied in the \(z\)- direction.
3. MATHEMATICAL MODEL

According to Kasprzak (2006), there are innumerable tire models in use around the world, which vary in complexity, scope and purpose. They can be based on detailed tire structural models, finite element calculations or semi-empirical equations. Purposes range from tire ride modeling, envelopment of road surface irregularities, tread shape analysis, rolling resistance calculations, tire dynamics, tire force and moment. All tire models in use have their own strengths and weaknesses, and applications to which they are well suited.

3.1 Magic Formula

The magic formula was developed during the second half of the 1980s by the Technological University of Delft in cooperation with "Volvo Car Corporation". The magic formula developed by Pacejka is widely used for empirical models and simulations. The magic formula can be used in modeling to calculate the tire forces and moments applied and there are several versions of this magic formula developed over these years of study. Over the years, the magic formula was further strengthened. Published by Pacejka and Bakker (1993) the general formula, which calculates the longitudinal force, the lateral force and the aligning torque in function of slip angle or longitudinal slip, is:

\[
y(x) = D \sin(C \arctan(Bx - E(\arctan(Bx))))
\]

\[
Y(x) = y(x) + S_y
\]

\[
x = X + S_h
\]

Where \( Y(X) \) represents the lateral force, longitudinal force or aligning moment and \( X \) denotes the slip angle or longitudinal slip, \( S_y \) and \( S_h \) are horizontal and vertical shifts, and \( B, C, D \) and \( E \) are, respectively, stiffness, shape, and peak curvature factors.

The tire model of PAC 2002 is the latest generation of the Magic Formula. The model PAC 2002 describing the behavior of tires traveling over relatively smooth road surfaces and its dynamical behavior is valid for frequencies up to 12 Hz. In this model the pneumatic trail is introduced as a basis to calculate the moment about the axis \( x \), overturning moment. This model presents non- dimension parameters as \( p, q, r \) and \( s \) and also the scale factor \( \lambda \). Thus the effect of the tire for different normal forces can be approximated using this factor of scale. Also the aligning torque is changed and based on combined slip.

According to Kuiper and Van Oosten (2007) the Magic Formula 2002 is used to steady-state cornering, single or double lane change, braking or power-off in a turn, \( \mu \)-split braking, \( j \)-turn or other turning maneuvers and ABS braking when the distance to stop is important.

4. DYNAMIC SIMULATION AND RESULTS

In order to analyze the dynamic behavior, it is used an engineering software addressed by MSC Adams®. In this software an approximation of the real wheelchair was made allowing the simulation of the behavior of this wheelchair for different types of the tire model.

4.1 Pacejka '89

The example of the Pac89 tire property file from MSC Adams® was adapted to fit the real wheelchair. In this simulation the same torque was applied at both driving wheels to generate a straight movement.
In this simulation the wheelchair starts to revolve on the spot instead of going straight ahead. That can be seen in the graphics of the Fig. 3 where the values of the lateral forces and the aligning torques are increasing and oscillating.

In Figure 3, the lateral force at the beginning of the movement started small between 0 and 20 N, but after some time presented with high values causing the wheelchair to make a curve. And this also happened in the castor wheels, shown by the red and blue lines. In the graph of aligning torque note that the torque on the castor wheel, represented by pink and black line, tends to be opposite to align the wheelchair in the beginning of the simulation, but after they tend to the same direction causing the curve. Doing the same simulation but now with changed coefficients of the magic formula \( a_i \) and \( c_i \), using the values from Genta (1997), results in a different behavior as it can be seen in Fig. 4.

Now the wheelchair goes straight ahead as shown in Fig. 4. In Figure 5 can be noticed that the lateral forces and the aligning torques keep at a level of numerical zero.
A Simulation with the same coefficients but a higher driving torque at the left wheel, results in a right turn, as expected:

Figure 6. Simulation of the wheelchair making a curve using Genta parameters

Because of this curve the lateral forces and the aligning moments increase in function of the curve that the wheelchair makes, as it is shown in the graphics of the Fig. 7. At the end of the simulation the radius of the curve becomes larger concerning to the value of the lateral force.

Figure 7. Lateral Force and Aligning Torque

4.2 Pacejka 2002

The first version of the Magic Formula only calculates lateral force ($F_y$) and aligning torque ($M_z$) as a function of slip angle ($\alpha$) and longitudinal force ($F_x$) as a function of longitudinal slip ($\kappa$). It doesn’t consider the rolling resistance, overturning moment, combined slip or the effects of inclination angle. The results of using the adapted example of MSC Adams of PAC 2000 are shown in Fig. 8.

Figure 8. Simulation of the Wheelchair using Pacejka 2002

For this simulation a constant torque is applied at both wheels, which results in a straight movement. In the graphs in Fig. 9 it is possible to see that the lateral forces at the castor and the large wheel at each side are of the same quantity but with opposite direction. This is necessary to align the wheelchair and generate a straight forward movement.
Increasing the applied torque at the left wheel for the same simulation parameters causes a right turn of the wheelchair:

The wheelchair makes a curve and goes on with the same radius. This can be noticed in the graphic of the aligning torques. The aligning torque at the left wheel with the higher driving torque increases and then become constant.

4.4 Experimental Test

Through simulations made with some different tires models noted the need for some specific parameters of the wheelchair tire. Thus was made a bench test for obtaining these parameters. Implementing parameters obtained by experiments and applying the same driving torque at the both wheels in the Pacejka 89 model with the aim that the wheelchair goes straight ahead:
But as in the first case the wheelchair makes a curve in the beginning, but then it starts to go backwards and the castor wheels get lost. In Figure 13 it is possible to notice that the lateral force and the aligning torque increase and oscillate. This probably occurs because of some imprecision in the measure of this coefficients used in the simulation. Thus better experimental parameters should be getting.

![Lateral Force](image1)
![Aligning Torque](image2)

Figure 13. Lateral force and Aligning torque in function of time using experimental parameters

5. CONCLUSION

The dynamic behavior study about the wheelchair is fundamental to give security and reliability for the wheelchair users. The modeling of the contact between the wheels and the ground was sufficient to show the behavior of the wheelchair. But in some models the wheelchair suffers a slip due or a strange behavior because of the used parameters.

In these simulations each model presented its advantages and disadvantages, and each model was best for one type of situation or behavior. Each is necessary for a general knowledge of the properties and characteristics of tires. For the modeling of the contact between tire and ground of a wheelchair a good knowledge of the real tires is required to have a closer simulation of reality.

6. ACKNOWLEDGEMENTS

The authors wish to thank the DAAD (German Academic Exchange Service) and CAPES (Committee for Postgraduate Courses in Higher Education of Brazil) which support the exchange of researchers in the frame of the PROBRAL (German - Brazilian cooperation project program).

7. REFERENCES


8. RESPONSIBILITY NOTICE

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