MMT Symposium
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June 26-28, 2024 | Guimarães, Portugal

DYNAMIC MODELING AND ANALYSIS OF A FORMULA STUDENT CAR WITH FOCUS ON THE FRICTION BEHAVIOR OF THE VEHICLE SUSPENSION SUBSYSTEM

Francisco Novais[1,2], Filipe Marques[1,2], Paulo Flores[1,2]

[1] CMEMS-UMinho, Department of Mechanical Engineering, University of Minho, Campus de Azurém, Guimarães 4804-533, Portugal, {novais.francisco01@gmail.com; fmarques@dem.uminho.pt; pflores@dem.uminho.pt}

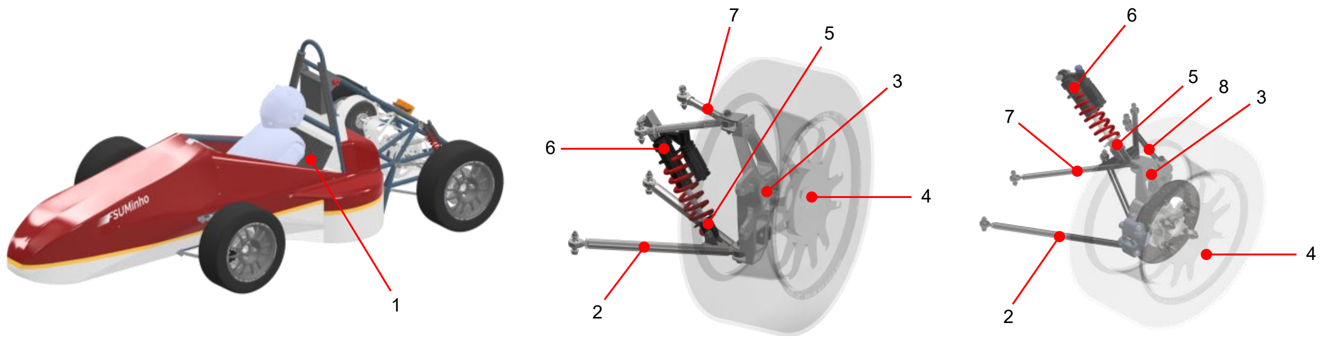
[2] LABBELS – Associate Laboratory, Braga/Guimarães, Portugal

1. INTRODUCTION

Friction is a complex phenomenon that appears as a tangential resistive force acting between contacting surfaces, which have relative motion. Friction has a nefarious effect on the dynamic performance of a large variety of mechanical systems, namely in terms of energy dissipation, noise produced, reliability, etc. Therefore, it is important to develop approaches that allow a detailed identification and prediction of friction influence on the dynamic behavior of multibody systems. Thus, the main scope of this work is to study the influence of friction force on the performance of a vehicle's suspension system. For this purpose, a multibody model of the University of Minho Formula Student (FSUM) car is utilized as an example of application. The requirements of the suspension systems are greatly dependent on the practical application, where two main categories can be distinguished, namely passenger vehicles and competition vehicles. For passenger vehicles, the design process focuses on gathering simulation data to create control algorithms for active suspension systems [1] and to define Noise, Vibration and Harshness criteria. Passenger comfort metrics are also defined, which will serve as target values to reduce the transmissibility of unwanted vibrations from the suspension and chassis systems to the vehicle's body [1]. In turn, as far as the competition vehicles is concerned, the prerequisites are quite different, since the main goal is to extract the maximum handling performance from the car, for which a deep knowledge of the suspension system dynamics is crucial to correctly define the setup of the shock absorbers in the presence of friction phenomena [2]. Several works available in literature describe experimental apparatus [3, 4] where the main sources of friction in shock absorbers are identified and studied in an isolated form. The experimental data collected is then compared with computational simulations results [1, 3] in order to develop better dynamic behavior prediction models. The use of multibody dynamics formulations constitutes an alternative and powerful approach to model road vehicles, allowing the simulation of different driving scenarios in which the transient handling response of the vehicle is strongly dependent on the realism of the suspension system's modeling [5]. The main focus of this work is to develop a multibody model of a formula student car, which allow to examine the dynamic response of the suspension subsystem taking into account the friction phenomenon.

2. VEHICLE MULTIBODY MODEL

The vehicle chosen in the present work is the single-seater prototype of FSUM team. Figure 1a shows the complete CAD model of the analyzed car. The suspension for both front and rear axles is of double wishbone (double A-arms) type, being the most common type of suspension utilized in race cars. Figure 1b depicts the left front suspension system of the car, and Figure 1c the isolated left rear suspension system. The different bodies of the model are numbered, and a description is given in Tab. 1.



(a) (b) (c)

Figure 1. (a) CAD model of the FSUM car; (b) Left front suspension system; (c) Left rear suspension system.

The right side of the vehicle was modeled considering the symmetry of the model. The complete model of the car is constituted by 27 bodies and associated with the suspension system a total of 44 mechanical joints have been defined between spherical, revolution and cylindrical joints. The Pacejka Magic Formula [6] tire model was chosen for this case study to model the tire interaction with the ground, and the parameters have been calibrated via curve fitting of experimental data. The vehicle dynamics analysis comprises a straight-line acceleration and braking tests, in order to study the effects of friction in the squat and dive behaviors of the car's suspension, a series of simulations that intend to replicate dynamic tests performed in a 4-Poster Test Rig and an obstacle avoidance maneuver, similar to a fast lane changing maneuver [5]. The multibody dynamics simulations of the model are performed in MUBODYNA 3D, which is an in-house MATLAB code to perform dynamic simulations of spatial multibody systems.

Table 1. Description of the bodies considered to model the left front and rear suspension systems of the FSUM car.

1	Chassis and Driver
2	Lower Suspension A-Arm
3	Upright/Wheel Knuckle
4	Wheel and Tire
5	Bottom Spring-Damper
6	Top Damper
7	Upper Suspension A-Arm
8	Toe bar

3. INCORPORATION OF FRICTION EFFECTS IN THE SUSPENSION SUBSYSTEM

A multibody system is a group of mechanical components that describe large translational and rotational displacements, in which the relative motion of the bodies is constrained by kinematic joints and force elements [7]. Some of the most relevant types of forces in multibody models are gravitational forces, external applied forces and moments, spring-damper-actuator forces, normal contact forces, tangential or frictional forces, and forces due to elasticity of bodies [7]. In this section, special emphasis is given to the spring-damper force element, since the main scope of this work is to analyze the dynamic behavior of the FSUM car's suspension system. Considering the friction effects, the total spring-damper force can be evaluated as

$$f^{\text{sda}} = k\left(l - l^{0}\right) + c\dot{l} + f^{\text{f}} \tag{1}$$

where the first term of the right-side member represents the spring force component, being k the spring stiffness, l the deformed length and l^0 the initial undeformed length of the spring, the second term is the damper force, where c is the damper damping coefficient and $\dot{l}$ is the time rate variation of the damper length, and, finally, the third term denotes the dry friction force that can be defined by different friction force models available in literature [8]. The two most common types of friction present in shock absorbers of vehicles are the viscous friction, which is the governing and intended working phenomena of a suspension system, as dissipates vibrations transmitted to the vehicle's chassis, and the solid dry friction, that is generated between the rubbing of damper's seals and guides against their counterparts during actuation [1]. The static friction verified in the seals requires a breakaway force to start movement, thus leading to a rigid performance of the damper until the applied force exceeds the stiction (static friction) level. Since shock absorbers are mounted parallel to suspension springs, the breakaway effect makes the suspension system inactive, causing wheel displacements to directly affect the vehicle's body, resulting in high accelerations that can affect the driver's steering inputs and overall control of the vehicle. The frictional behavior, influenced by shock absorber and seal design, is a complex phenomenon, making it hard to predict. At high velocities, static friction's impact on the overall damping force is minimal, so it is mainly relevant at low actuation speeds [1]. The focus of this study is centered on the low-speed and small-displacement ranges of shock absorbers working conditions where dry friction phenomena are preponderant.

ACKNOWLEDGMENTS

This work has been supported by Portuguese Foundation for Science and Technology, under the national support to R&D units grant, with the reference project UIDB/04436/2020 and UIDP/04436/2020.

REFERENCES

[1] L. Herzog and K. Augsburg, "Study on Friction in Automotive Shock Absorbers Part 1: Friction Simulation Using a Dynamic Friction Model in the Contact Zone of an FEM Model". *Vehicles*, 3(2), 212-232, 2021.

[2] C. Benini, M. Gadola, D. Chindamo, S. Uberti, F.P Marchesin and R. S. Barbosa, "The influence of suspension components friction on race car vertical dynamics". *Vehicle System Dynamics*, 55(3), 338-350, 2017.

[3] J. Lizarraga, J. A. Sala and J. Biera, "Modelling of friction phenomena in sliding conditions in suspension shock absorbers". *Vehicle System Dynamics*, 46, 751-764, 2008.

[4] L. Herzog and K. Augsburg, "Study on Friction in Automotive Shock Absorbers Part 2: Validation of Friction Simulations via Novel Single Friction Point Test Rigs". *Vehicles*, 3(2), 197-211, 2021.

[5] J. Ambrósio and P. Verissimo, "Improved bushing models for general multibody systems and vehicle dynamics". *Multibody System Dynamics*, 22(4), 341-365, 2009.

[6] H.B. Pacejka, *Tire and Vehicle Dynamics*. Butterworth-Heinemann, 2012.

[7] P. Flores, *Concepts and Formulations for Spatial Multibody Dynamics*. Springer International Publishing, 2015.

[8] F. Marques, P. Flores, J.C. Pimenta Claro and H.M. Lankarani, "A survey and comparison of several friction force models for dynamic analysis of multibody mechanical systems". *Nonlinear Dynamics*, 86(3), 1407-1443.