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Measurement of wheelchair contact force with a low cost bench test

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ABSTRACT

In mechanical engineering, it is well established that contact between the tire and the ground is a key parameter in characterizing the dynamic behavior of vehicles and an important factor in design control. Therefore, it is an important part of dynamic simulation models for vehicles, including wheelchairs. This work presents a bench test designed to experimentally monitor and measure the forces transmitted to the ground by a moving wheel. The test bench is composed of a table and a track with a fixed wheel structure and powertrain system. The table is an integrated structure that measures the longitudinal and lateral forces produced by tire contact. This table allows characterization of the tire and tests the tire under varying loads at different slip and camber angles. Additionally, the test bench can also be used to evaluate other tires, such as caster tires. The performances of the new device are illustrated, and the results show the differences between tires, which are related to the dynamic behaviors of wheelchair model. Finally, preliminary experiments performed using the test bench have shown that it is able to monitor and measure the forces generated by the contact between the tire and the ground.

1. Introduction

Recent advances have dramatically improved the quality of life for wheelchair users, from accessibility to overall ride comfort. However, important aspects of wheelchair use are not well understood. Insight into wheelchair behavior could help the designers improve the wheelchair's comfort and reliability.

Ground vehicles are those vehicles that are supported by the ground, in contrast with aircraft and marine craft, which in operation are supported by air and water, respectively. The ground vehicle is becoming an increasingly common transportation method for humans in the world [1]. With increasing ground vehicle use, researchers have advanced technology to improve safety and comfort. The progression of these studies has revealed that the tires are one of the most important components of a vehicle. Tires are in direct contact with the ground, and the contact area between the tire and the ground allows for the propulsion, braking and cornering of the vehicle [2–4]. Therefore, the tire is closely associated with stability, comfort and performance.

According to Cabrera et al. [5], the dynamic behavior of vehicles is predominately influenced by the properties of the tire, as longitudinal and lateral force and aligning moment. Therefore, knowledge of these properties is important to correct vehicle behavior and develop advanced control systems. Mathematical models of tires are used to simulate the dynamic behavior of a vehicle. However, the structural complexity and nonlinearity of tires make it extremely difficult to establish a theoretical model that accurately describes the various mechanical properties of the tire under different operating conditions.

The same concept for automotive tires should be applied to wheelchairs. Although tires are an important part of the vehicle that significantly affect wheelchair propulsion sometimes they are not considered in the studies and in the dynamic models. Previous studies have clarified the effects of tire type, tire pressure, camber angle and surface on the rolling resistance of wheelchair tire [6–8].

Simulations, experiments and observations have determined that tire properties significantly affect wheelchair behavior. For example, wheelchair users predominately prefer pneumatic wheels over rigid wheels, even though rigid tires do not require any maintenance [8,9]. However, Gordon et al. [10] presented two new polyurethane foam tires that behave similar to high-pressure pneumatic tires.

Experimental techniques are required to determine the parameters of the tire model, and the tire forces and moments are generally measured by constrained laboratory tests and on-road testing machines [11]. Sometimes it is necessary to build an experimental bench to survey these parameters. State of the art tire test benches [11–14] can be divided into three basic types (Fig. 1): drum type, flat belt and flat bed.

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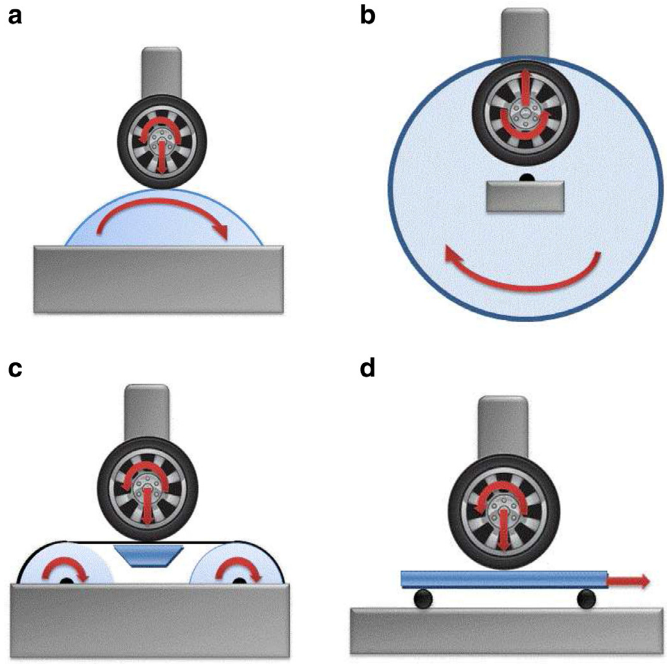

Fig. 1. Schematic illustrations of the basic types of tire bench tests: (a) drum type (outer), (b) drum type (inner), (c) flat belt and (d) flat bed.

Drum test benches are generally used because they are cheap, straightforward to use and easy to construct. The drum simulates the road, and the tire can roll on either the outer or inner surface of the drum. The tire contact, or footprint, varies depending on the drum's position. The footprint can be a curve, and this curvature can alter the distribution of pressure. To avoid different contact conditions, other types of test benches have been developed, such as the flat belt and the flat bed. However, flat belt benches are more expensive, and it is more difficult to alter the road materials for flat belt benches.

The aim of the present study is to demonstrate that the contact force varies depending on the type of tire and floor surface, as found in the previous work [15], and to evaluate the magnitude of this variation. Therefore, this study presents a low-cost device that measures the lateral and longitudinal forces and the self-aligning moment for different tire types, floor surfaces and angles.

This study focuses on lateral wheelchair behavior, which is not usually considered in wheelchair dynamics but significantly influences turning maneuvers.

2. Methods

The tire is the only component responsible for transferring forces and moments between the wheelchair and the ground. When studying the resistance to manual wheelchair motion, the motion is generally limited to linear movements, however, there are various situations in which rotation of the wheelchair occurs. When a turn is initiated, through either differential power to drive the wheels or manually pivoting steerable wheels, the tires develop a lateral force, which turns the wheelchair. Because determining the lateral forces on tire cornering is considered the most difficult task in vehicle modeling, this work focuses on lateral dynamics. According to Gadola et al. [16], the slip angle (α) is a key parameter in lateral vehicle dynamics and it is crucial for vehicle stability and handling. The slip angle is the angle between the tire and the actual directional path of the tire.

However, to study the contact between the tire and the ground, other characteristics should be described. The camber angle (γ) is the angle between the wheel plane and the perpendicular plane to the ground, or the wheel tilt. The lateral force (F_y) is the resultant of the force produced by the camber angle and the slip angle (Fig. 2).

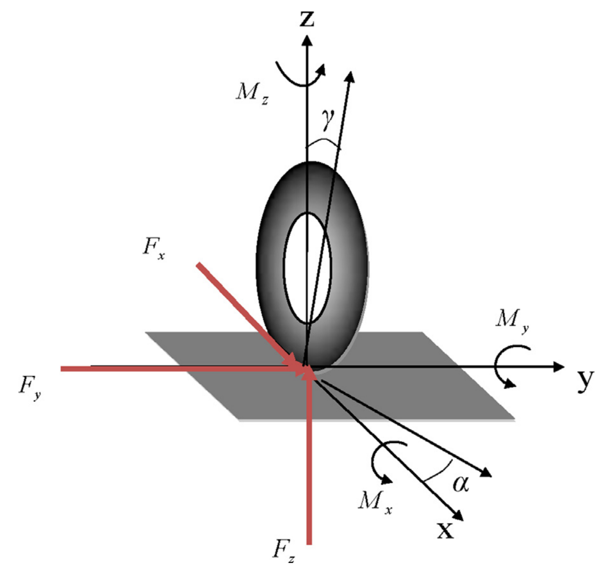

Fig. 2. Reference frame for tire forces and moments.

Another important factor is the normal force, which is the vertical force applied to the tire. The last factor is the self-aligning moment (M_z), which is the torque produced by the tire as it tries to return to its original path direction.

2.1. New test bench and instrumentation

A small research group with mounting interest in the field of wheelchair dynamics has developed a tire testing device [17]. This new approach draws on the advantages of the test benches presented in Fig. 1. It is as simple to use and low cost as a drum test machine, but with the ideal contact of flat test machines.

The proposed bench is able to test rigid and pneumatic tires 10 to 70 cm in diameter that are operating at low speeds and low load capacities. For higher speeds and larger loads, several modifications should be made to the table structure. The experimental apparatus (Fig. 3) consists of following:

- Three load cells: two for lateral force measurements and one for longitudinal force measurements.
- Table with 2 degrees of freedom for tire rolling (unrestricted movement in planar direction).
- Four-bar mechanism (four links) [18] that it is linked to a powertrain system on the wall to apply loads to the fixed wheel.
- Control system.
- Data acquisition system (signal conditioning and processing).

In testing machines, the tire is generally fitted to a hub that includes a device that measures the three force and moment components [19]. In this new test bench, the longitudinal and lateral forces are measured directly in the table as the tire rolls over.

Fig. 4 shows a detailed description of the components and the positions of the load cells. The load cells are transducers, which are usually used in force measurement. Its operation is given by the variation in resistance and deformation of gauges, which makes the output voltage proportional to strain. Two cells are located on the table side for lateral force measurement, and one load cell is placed on the front table for longitudinal force measurement (Fig. 4a). Two types of Dual Load Cells were used one with 445 N of capacity and another with 4450 N of capacity. For improved performance, the load should be applied without any side load or torque; therefore, rods