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Modeling and Analysis of Bicycle Equipped with In-Wheel Suspensions

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ABSTRACT

The most common bicycle mechanical failure is a flat tire. To minimize the risk of flat tires, some manufactures have adopted solid tires. Solid tires greatly reduce maintenance cost, but yield a rigid and less comfortable bicycle. This paper analyzes a possible solution to the issue: an in-wheel suspension system. Each wheel is composed of three spokes equipped with a spring and a damper and a solid tyre. The manufacture's main claim is that the suspension can provide good road filtering even with solid tires. The paper develops a multi-body model that focuses on the in-plane dynamics and uses the model to study the effect of the in-wheel suspension under three main aspects: road filtering, efficiency and riding dynamics. The analysis shows that the suspension system improves comfort but reduces the average vehicle efficiency of 10% and introduces harmonic pitch perturbations while riding.

Keywords: bicycle dynamics, suspension systems, in-wheel suspensions

1 INTRODUCTION

Two factors determine the worth of a city bike: robustness and ride quality. Robustness (or sturdiness) means reliability and reduced maintenance costs. Ride quality is mainly determined by frame weight (mainly affecting cycling effort) and tires (affecting road roughness filtering and pedaling effort). Tires play a critical role in both aspects. Two families of tires exist: pneumatic tires and airless tires. Pneumatic tires [5] guarantee good comfort and lower pedaling effort but are subject to punctures. Airless tires are in general more robust but provide a lower quality riding experience mainly because of their stiffness and inability to filter road roughness.

The loss of comfort caused by airless tires can be offset by introducing suspensions. The research on this topic mainly deals with the development of models and performance assessment [9, 10, 4, 2]. This body of work proves that suspensions can indeed improve ride comfort over rough terrains. Their main disadvantage is that they require modifications to the bicycle frame.

This paper studies a novel solution that has been recently proposed: in-wheel suspensions. The basic idea is to add flexibility to an airless tire by installing three supporting spokes, each of them equipped with a spring and a damper. This architecture allows the central hub to modify its pose according to external disturbances (road induced vibrations, load perturbations, etc.). The paper develops a multi-body model of the in-plane dynamics of a bicycle equipped with two in-wheel suspensions. The model accounts for all the bicycle and wheel components and considers a rigid cyclist. In particular, the model describes the effect of the road profile and the cyclist's torque on the vertical, longitudinal and pitch dynamics.