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In-depth analysis of bicycle hydraulic disc brakes

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ABSTRACT

Hydraulic Disc Brakes (HDBs) represent the most recent and innovative bicycle braking system. Especially Electric Bicycles (EBs), which are becoming more and more popular, are equipped with this powerful, unaffected by environmental influences, and low-wear type of brakes. As a consequence of the high braking performance, typical bicycle braking errors lead to more serious accidents. This is the starting point for the development of a Braking Dynamics Assistance system (BDA) to prevent front wheel lockup and nose-over (falling over the handlebars). One of the essential prerequisites for the system design is a better understanding of bicycle HDBs' characteristics. A physical simulation model and a test bench have been built for this purpose. The results of the virtual and real experiments conducted show a high correlation and allow valuable insights into HDBs on bicycles, which have not been studied scientifically in any depth so far.

1. Introduction

Bicycles were introduced in 1817 by Karl Drais. His invention comprised a two-wheeled, steerable human powered machine commonly called Draisienne. When John Starley introduced his Rover III safety bicycle – two small similar-sized wheels, rear wheel chain drive, and direct steering – in 1888, the modern bicycle, as it is known today, was born. While the freewheel hub invention by Ernst Sachs in 1898 increased cycling comfort considerably, a separate brake became necessary.

1.1. Hydraulic braking systems

In 1987 the German manufacturer Gustav Magenwirth GmbH & Co KG, better known under the brand name Magura, introduced the first hydraulic rim brake. Since that date hydraulic braking systems on bicycles have been used more and more frequently. The biggest advantages are comparatively lossless power transmission and almost maintenance-free operation. Nowadays, HDBs are state-of-the-art components in a wide range of conventional high-quality bicycles and electric bicycles (EBs). The main reasons are a high vehicle deceleration with only very small actuation forces by the rider and optimal adjustment of the friction pair pad and disc. Compared to rim brakes, HDBs are also less sensitive to environmental influences such as a wet road. This is due to a variety of reasons, including the further distance of the friction area from the road.

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Furthermore, the holes in modern bicycle brake discs provide form closure with the elastic brake pads, which are less affected by water than the exclusively friction based rim braking.

1.2. Scientific literature

There is a lack of in-depth analysis of transmission behavior and most influencing factors of HDBs for bicycles in scientific literature. Kahn et al. [1] modeled a hydraulic braking system for motor vehicles containing a vacuum booster. Kahn obtained the validation data from a test bench. Gerdes and Hedrick [2] developed a simulation model of a hydraulic brake system for motor vehicles. The key objective of the model was to perform dynamic investigations and use these for model-based controller design. Kuang et al. [3] presented a simulation model of a hydraulic braking system which supports the design process of vehicle control systems as well. Yang et al. [4] developed a simulation model of the hydraulic braking system to find the critical design parameters and to support the design process. Qi et al. [5] investigated the influence of several parameters on the braking effect by developing a hydraulic braking system model which contained an anti-lock braking system. Fisher [6] designed a complex simulation model of a hydraulic braking system to study the dynamic performance of components of a hydraulic brake. In summary the research activities are focused on motorized vehicles and motorcycles.

1.3. BikeSafe-project and content summary

The availability of electrical energy on EBs, in contrast to conventional bicycles, offers a variety of opportunities for safety improvements. This is the fundamental idea for the interdisciplinary research project BikeSafe. It aims at the development of a Braking Dynamics Assistance system (BDA) for bicycles equipped with HDBs. The BDA to be designed will address two major braking errors: front wheel lockup and nose-over (falling over the handlebars).

This paper presents an in-depth analysis of HDBs. A physical simulation model with all assumed influences has been built up for this purpose. A test bench has been developed simultaneously for purposes of model validation and research into physical effects not covered by the model. The brake system under test was the popular Magura MT 4 with the brake disc Storm Rotor 180 mm. Specific characteristics of this brake are: one-piece brake caliper with two-pistons, organic brake pads and use of mineral oil as hydraulic fluid. The results of virtual and real experiments match very well and show the most influential factors regarding hydraulic transmission behavior. Further improvements of the virtual and real test setup are proposed and an outlook on the next possible research steps is given.

2. Material and methods

2.1. Simulation model

2.1.1. Degree of abstraction and software selection

There are four degrees of abstraction for simulation models in modeling theory: topological, physical, mathematical, and numerical (cf. Fig. 1).

Choosing the right degree of model abstraction is based on the objectives of the in-depth analysis of HDBs:

- Understanding the fundamental static and dynamic transmission behavior
- Identification and sensitivity analysis of the most influential parameters

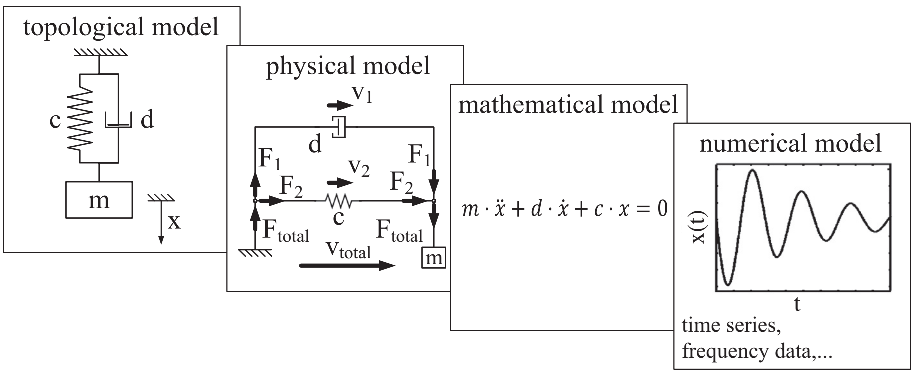

Fig. 1. Abstraction levels of simulation models [7].