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*Conference Abstract*

# A laboratory treadmill for simulation of road surface induced vibrations in cycling

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**Abstract:** Within the framework of a systematic approach, a novel test setup for the simulation of road surface induced vibrations was developed. This can be used for various questions concerning the oscillatory system cyclist-bicycle. The innovation compared to the state of the art is the separate introduction of vibrations at the front and rear wheel while at the same time enabling a natural riding behavior during pedaling and coasting, even at higher speeds.

**Keywords:** Bike, Test bench, Test rig, Roller trainer, Pneumatic actuation, Dynamics

## 1. Introduction

During cycling on various paved surfaces, the roughness of the ground excites vibrations that are perceived by the rider. The transmission of vibrations within the bicycle structure as well as to the cyclist, and technical possibilities of influencing them are the subject of research and development.

Field testing can provide insights into the human response to vibration, such as an increased work done and reduced economy of human movement when comparing cycling on smooth and rough roads (Macdermid, Fink, & Stannard, 2015). However, the large number of variables involved makes naturalistic reproduction of these conditions very difficult. One approach to overcome this limitation is to transfer the vibration conditions from reality to laboratory tests.

In their study, Lépine et al. utilized a test bench consisting of two hydraulic shakers positioned under the wheels to vertically excite a bicycle. The wheels were not fixed to the shakers, but instead rested freely on top of the shaker heads. During measurements, the cyclist remained seated on the bicycle, which was kept vertically stable using bungee cables. The cables were wrapped around the seat tube and attached horizontally to a fixed structure on each side of the bicycle. The position of the cables was carefully chosen to ensure compliance in the vertical direction, thus avoiding any impact on the bicycle's dynamics in that direction. The bungee cables could hold both the cyclist and the bike in a stable and upright position. (Lépine, Champoux, & Drouet, 2015). The biggest limitation here is the lack of pedalling movement and rotation of the wheels. This makes the additional lateral fixation necessary.

In a study by Petrone et al. (2015), the combination of a servo-hydraulic actuator and a free roller trainer allowed to overcome the limitations of a cyclist sitting passively on the bicycle (Petrone, Trabacchin, & Panizollo, 2015). On a free roller trainer, a cyclist can use a standard unmodified bicycle. The bicycle rolls stationary with its rear wheel in a gap between two rollers and on a co-planar third roller with its front wheel. This set up is commonly known and used as warm up device in road and track cycling. The limitations in the experimental setup of Petrone et al. (2015) can be seen in the exclusive excitation at the rear wheel and in the comparatively small drum diameter of the roller trainer. The latter leads to a strong deformation of the tires even at high pressures above 8 bar, which results in increased flexing work. This restricts actual coasting without pedalling. At the same time, it can be assumed that such a strong deformation of the tire compared to the field leads to significantly deviating dynamic behaviour of the tire and thus of the overall rider-bicycles system (RBS).

In this paper, an approach will be presented that allows riders to cycle freely on a laboratory treadmill-like device, stimulating the RBS in a way that represents field-like conditions in terms of vibration excitation, pedalling style, and coasting abilities.

## 2. Methods

The methodical development of the test rig was closely following the corresponding guidelines 2221, 2222 and 2225 (each part 1) of the Association of German Engineers (VDI). The VDI 2221 guideline provides for a total of four phases, that were passed through during the project to develop the test stand:

Phase 1: Planning,
Phase 2: Conception,
Phase 3: Design, and
Phase 4: Elaboration.

## 3. Results

### *3.1 Overview*

A roller trainer platform (RTP) was developed with the goal to allow a maximum of free, unsupported, lateral movement and an improved riding stability at field relevant velocities. The targeted velocity was set to range from 25 km/h upwards and to be maxed out at ~55 km/h. The stability of the RBS can be maintained within this speed range by any subject.

The RTP (cf. Fig. 1) has various parts and assemblies, which are described in more detail below. Essentially, these are a base frame made of aluminium strut profiles (No. 1 in Fig. 1), a rear (2) and front (3) unit carrying rotatably mounted drums (4 & 5), a belt drive (6), pneumatic drives (7 & 8), linear guides (9 & 10), and a bicycle (11).

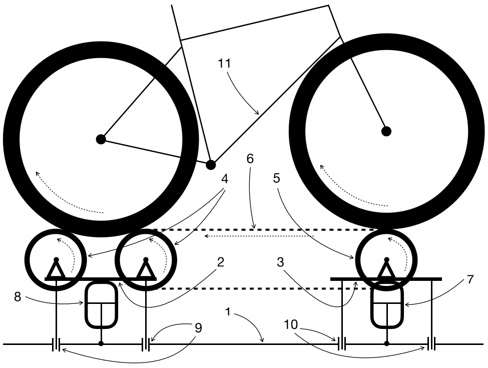

**Figure 1**. Schematic representation of the experimental setup in lateral view

In addition, the experimental setup has safety features such as plates to cover pinch and catch points, and a restraint system for the test subject in case of a fall (cf. Fig. 2).

**Figure 2**. Initial tests

### *3.2 Riding*

The RBS is in contact with its front wheel on a single drum (FWD, diameter 200 mm, width 800 mm), while the rear wheel runs in a gap between two further drums (RWD) of the same dimensions. The distance between the front and rear wheel drums is adjusted according to the wheelbase of the bicycle so that the front wheel's vertical axis equals the front wheel drum's axis. When riding on this roller trainer, the bicycle's rear wheel sets the RWD into rotation. An elastic belt then transfers the rotation of the RWD to the FWD simultaneously.

### *3.3 Excitation*

The vertical position (z-level) of the front and rear units can be altered independently from each other over time. Therefore, a pair of fluidic muscles (Festo Vertrieb GmbH & Co. KG, Esslingen, Germany), hermetic polymer tensile actuators with contraction characteristics, is engaged to each of the units.

The muscles are connected to electrically actuated valves, which can maintain two states: fill and release. A set of solid-state relays (SSR) is used to power the valves. The SSR input channels receives a pulse width modulated signal (PWM) from a signal generator. The pulse duration of the square wave signal determines the amplitude of the mechanical oscillation. The period of the switching signal, on the other hand, determines the frequency of the excitation. The current set-up is capable to excite the RBS (weight: 85 kg) within a frequency range of 0 Hz up to 18 Hz with amplitudes of up to 7.5 mm. The actual elongation of the two units is determined in each case using a laser distance sensor (AWLG 300 M, Welotec GmbH, Laer, Germany).

In addition to the signal parameters, the pressure in the pneumatic system can be altered from 3 bar to 8 bar to accommodate different RBS weights and weight distributions.

## 4. Discussion

The proposed test device enables a more realistic simulation when compared to solutions available in literature (Lépine, Champoux, & Drouet, 2015; Petrone, Trabacchin, & Panizollo, 2015). In fact, it facilitates the independent actuation of front and rear wheel of the bicycle while allowing the rider to pedal in an unconstrained manner. This is also endorsed using over-sized drums that results in a higher inertia and therefore increased stability of the RBS. The application of fluidic muscles and standard structural elements allows an easy-to-modify design that provides a flexible solution in terms of adaption to different test designs. In addition, pneumatic actuation is associated with lower acquisition and maintenance costs when compared to hydraulic or electric driven units.

Due to their characteristic inertia, pneumatic valves limit the test in frequency range to a maximum of 20 Hz (electric / coil actuated). Nevertheless, this frequency range still allows reproduction of surface induced vibrations.

It is noteworthy that the compressible medium used for actuation shows limitations in force rising rate, this increases the time required to reach the maximum force.

## 5. Practical Applications.

The presented test set-up suggests being suitable for a variety of applications: (i) behaviour of bicycle frames and components when exposed to field-relevant vibrations; (ii) investigation of vibration-induced cyclist’s fatigue; (iii) test of cycling garments with regards to vibration reduction; (iv) determine tires rolling resistance in realistic and replicable conditions.

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**Conflicts of Interest:** The authors declare no conflict of interest.

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