Indoor Test-Rig to Measure the Lateral Characteristics of Bicycle Tyres

Dell'Orto, Gabriele; Mastinu, Giampiero

DOI
10.1007/978-3-031-70392-8_128

Publication date
2024

Document Version
Final published version

Published in
16th International Symposium on Advanced Vehicle Control

Citation (APA)
Dell'Orto, G., & Mastinu, G. (2024). Indoor Test-Rig to Measure the Lateral Characteristics of Bicycle Tyres. In G. Mastinu, F. Braghin, F. Cheli, M. Corno, & S. M. Savaresi (Eds.), *16th International Symposium on Advanced Vehicle Control : Proceedings of AVEC 2024 – Society of Automotive Engineers of Japan* (pp. 911-918). (Lecture Notes in Mechanical Engineering). Springer. https://doi.org/10.1007/978-3-031-70392-8_128

Indoor Test-Rig to Measure the Lateral Characteristics of Bicycle Tyres

Gabriele Dell'Orto[1,2](✉) and Giampiero Mastinu[1]

[1] Department of Mechanical Engineering, Politecnico di Milano, Via La Masa 1, 20156 Milano, Italy
gabriele.dellorto@polimi.it
[2] Faculty of Mechanical Engineering ME, Delft University of Technology, Mekelweg 2, 2628 CD Delft, The Netherlands

Abstract. Tyre characteristics can strongly affect bicycle dynamics, therefore the overall bicycle performances. However, it may be hard to measure lateral characteristics with low uncertainty. Proper test-rigs are needed to obtain reliable tyre parameters, to be used then for modelling. The paper presents VeTyT, acronym of "Velo Tyre Testing", a new test-rig specifically developed for bicycle tyres at the Department of Mechanical Engineering of Politecnico di Milano. It is the first test-rig for bicycle tyres in compliance with the standard ISO 9001-2015. We also present the results of an experimental campaign conducted on a road racing bicycle tyre. In particular, the impact of rim stiffness is relevant to tyre characteristics, leading to a 13% increase in cornering stiffness under the same test conditions.

Keywords: Tyre · test-rig · modeling · lateral characteristics · bicycle

1 Introduction

The use of bicycles as a cheap and healthy way to travel the "last mile" is widely spreading in cities. This new way of dealing with short trips in the city, labeled "micro-mobility", is even fostered by the new awareness on the global impact of ICE vehicles as well as the fluctuations of fuel prices.

As the popularity of two-wheeled vehicles grows, concerns about road safety are growing as well. Injuries related to bicycle and moped falls have increased in recent years, enlightening the need to prevent them with proper strategies. With the aim of improving the self-stability and deepening the knowledge on bicycle dynamics, advanced numerical models are required [1, 2]. Furthermore, existing mechanical models of bicycles mostly ignore tyre dynamics and need to be complemented with realistic tyre models [3]. Therefore it is necessary to characterize bicycle tyres to proper understand the bicycle dynamics. At the Department of Mechanical Engineering of Politecnico di Milano, a new test bench has been designed specifically for the characterization of bicycle tyres [4–6]. It is possible to measure the lateral force and the self-aligning torque at varying slip and camber angle, vertical load and inflation pressure.

G. Mastinu et al. (Eds.): AVEC 2024, LNME, pp. 911–918, 2024.
https://doi.org/10.1007/978-3-031-70392-8_128

The aim of this study is present a new test-rig able to ensure accurate measurements on bicycle tyres lateral characteristics, varying working parameters such as vertical load and inflation pressure. This may be really useful to assess tyres, and set the proper strategy for improving both performances and bicycle stability. A number of previous works on test-rigs for bicycle tyre testing have been investigated in the last decades [5]. The still existing gaps are as follows. First, the values of uncertainty are generally not declared. Second, there is the request of both accuracy and data production efficiency. Reliable tyre data have to be exploited both by tyre and bicycle manufacturers. VeTyT tries to bridge the gap between accuracy and efficiency.

We also present the verification procedure of the test-rig, necessary to fulfill the requirements for ISO 9001 (Sect. 3). In Sect. 4, we show the results of an experimental campaign conducted on a 26 mm wide road racing bicycle tyre. In particular, we focus on the impact of inflation pressure and rim stiffness to the cornering stiffness (Sect. 4).

2 Test-Rig

VeTyT (short of "Velo Tyre Testing") is a testing machine specifically designed for bicycle tyres (Fig. 1). It can measure lateral forces and self-aligning moment of bicycle type tyres, varying many parameters, including slip angle α, camber (or lean) angle, and vertical load. It consists of a welded Aluminum 6060 T6 square-section bars, reinforced with plates and steel rods to ensure lightness and sufficient stiffness. It is connected to the ground by means of Watt's linkage (Fig. 2(a)) and universal joint. The kinematics of Watt's linkage allows for a sufficient vertical displacement while it constrains the lateral motion of the structure. The lateral force F_y can be derived by mounting two load cells in between rods.

VeTyT has been conceived so that the longitudinal axis passes from the universal joint, the contact point tyre/surface and the center of the Watt's linkage (Fig. 2(b)). In this way, by rotating a shaft rigidly connected to the universal joint, the camber angle can be set. Furthermore, this solution allows compensating vertical vibrations of the wheel due to unevenness on the rolling surface. The tyre/road contact point can be displayed only in vertical direction, resulting in zero longitudinal speed [1].

The test-rig can be placed both on a drum or on a flat track (Fig. 1). The drum has an outer diameter of 2.6 m, and it can reach a peripheral speed of 122 m/s. The flat track consists of a poly-V belt moved by a 5 kW three-phase asynchronous electric motor. A maximum speed of 21 m/s can be achieved. An aluminum plate supports the flat track belt in the contact region. Pressured air mixed with silicone oil is blown between the plate and the flat track belt to reduce the friction. As the shape of a bicycle tyre contact patch is similar to an ellipse [7], i.e. narrow and elongated, the flat track results the best tool to appreciate the forces exchanged along the entire contact area.

In addition to standard commercial rims, the apparatus has been designed to accommodate special high-stiffness laboratory rim (the one mounted on in Fig. 2). In this way, the compliance of the rim does not affect the experimental measurements.

A vertical shaft used to hold the wheel represents the vertical axis of VeTyT. It crosses the longitudinal axis in the contact point tyre/surface (Fig. 2). The slip angle α can be adjusted by rotating the steering shaft. Once the desired slip angle is set, the position can be fixed, and the test can start. An axial load cell used to fix the set slip angle measures the reaction force generated by the steered tyre. The self-aligning moment can be derived being the distance between the steering shaft axis and the load cell longitudinal axis known. The vertical load acting on the wheel can be varied by adding masses on the frame. Its magnitude F_z is recorded by a load cell positioned at the top of the steering shaft.

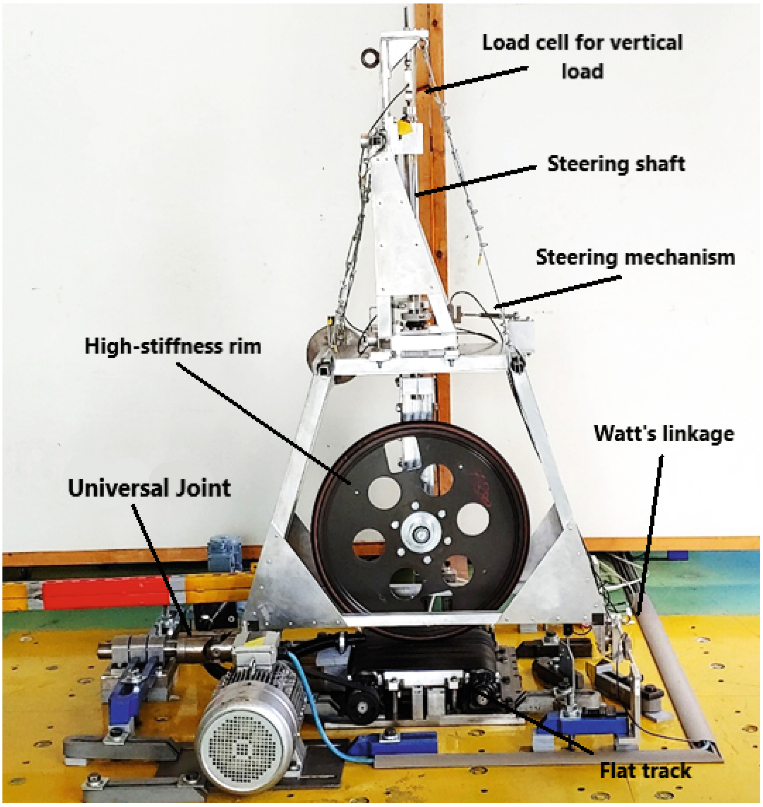
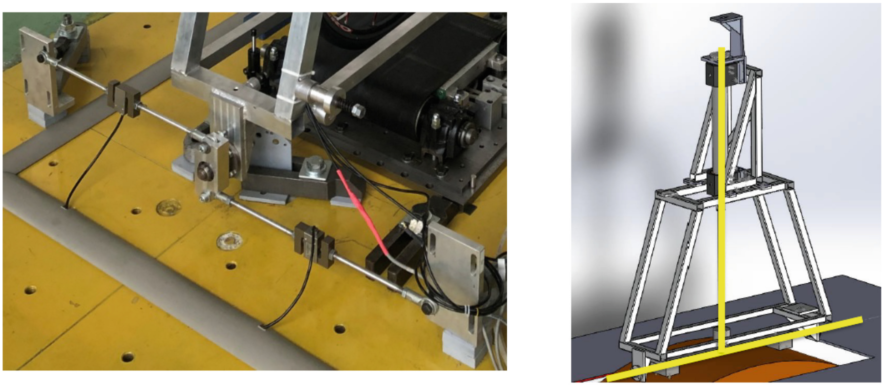


Fig. 1. VeTyT test-rig. The frame carries the bicycle tyre running on flat track. In this picture, tyre is mounted on high-stiffness laboratory rim [7].

3 Static Verification

VeTyT has been statically verified, to ensure the effectiveness of the measurements. In this way, we can compensate for any possible systematic error. The procedure has been conducted both for lateral force and self-aligning torque by using special set-up (Fig. 3).

Regarding the lateral force, the fork for commercial rim was mounted on the steering shaft. It was loaded with a treaded bar in series with a load cell, proper placed to ensure



(a) (b)

Fig. 2. (a) Watt's linkage on VeTyT. The central part is connected to VeTyT, the rods with load cells are fixed to the ground [4]. (b) VeTyT main axes are enlightened in yellow. The vertical axis defined by the steering shaft crosses the longitudinal axis in the center of tyre contact patch [4].

the perpendicularity with respect to the longitudinal axis of VeTyT. Assuming the self-aligning torque equal to zero by hypothesis, the applied force was compared to the actual value of lateral force given by the test-rig [4]. The measured force was found to be slightly higher than the applied one, for a systematic error of about 4.5 N. Referring to accuracy, the lateral force read by VeTyT corresponds to the actual applied force with a mean error less than 0.3%. Referring to precision, the standard deviation is less than 2% with respect to the mean value.

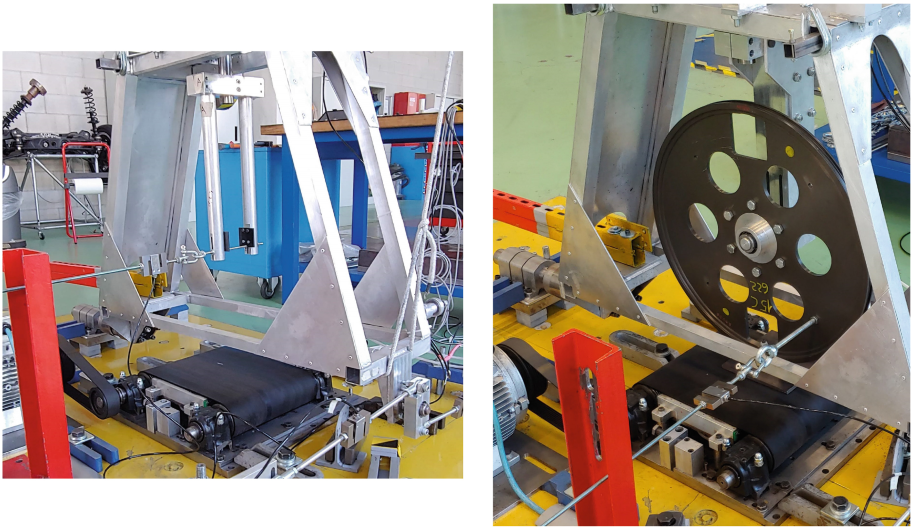
As for the self-aligning torque, we used the high-stiffness rim and an instrumented threaded bar fixed at a given distance from the hub. The torque can be generated by applying a force to the bar. Then, we measure the output given by the test-rig VeTyT [4]. The measured self-aligning torque was underestimated with respect to the actual torque applied. The deformation of chassis during the tests may slightly misalign the bearings, thus increasing the declared friction. During experimental tests, the maximum difference between measured and applied torque was equal to 0.55 Nm.

In this case, referring to accuracy self-aligning torque measured by VeTyT corresponded to the actual applied torque with a mean error lower than 1%. The standard deviation was found to be less than 2.5% with respect to the mean value.

4 Tests and Results

Several tests can be conducted with VeTyT. The static tests involve tyre not rolling on the contact surface, e.g. tyre deflection and contact patch measurements varying inflation pressure and vertical load. The dynamic tests are performed with tyre rolling on the contact surface to measure the lateral force and the self-aligning torque [8]. In this paper, we focus on dynamic tests, in particular on the role of rim stiffness and inflation pressure on the cornering stiffness C_{F_y}.

We conducted the test on a 26 mm wide road racing bicycle tyre, under different vertical loads, inflation pressure and mounted on a commercial aluminum rim and the



(a) (b)

Fig. 3. (a) Watt's linkage on VeTyT. The central part is connected to VeTyT, the rods with load cells are fixed to the ground. (Adapted from [4]) (b) Set-up used to verify the measurement of self-aligning torque. We used the high-stiffness rim with a threaded bar fixed to the rim at a known distance from the hub. (Adapted from [4]).

laboratory high-stiffness rim. The latter is approximately five times stiffer in lateral direction than a standard aluminum rim [8]. Flat track surface was covered by sand of controlled granulometry (1.2 mm).

The value of C_{F_y} largely changes with inflation pressure. As depicted in Fig. 4, the values at inflation pressure of 7.5 bar are higher than those at inflation pressure of 3.5 bar. The peak of cornering stiffness for inflation pressure 7.5 bar corresponds to the maximum tested vertical load of 490 N. As for lower inflation pressures, the peak of cornering stiffness can be found for lower vertical loads. Mounting the same tyre on high-stiffness rim (also named "Rigid rim"), we obtain larger values of cornering stiffness under the same test conditions (inflation pressure and vertical load, Fig. 5). Independently on the inflation pressure or on the vertical load, the value of C_{F_y} is on average 13% higher for the high-stiffness rim. The values of cornering stiffness C_{F_y} were then interpolated with high-order polynomial, to show the trend of cornering stiffness over the applied vertical load.

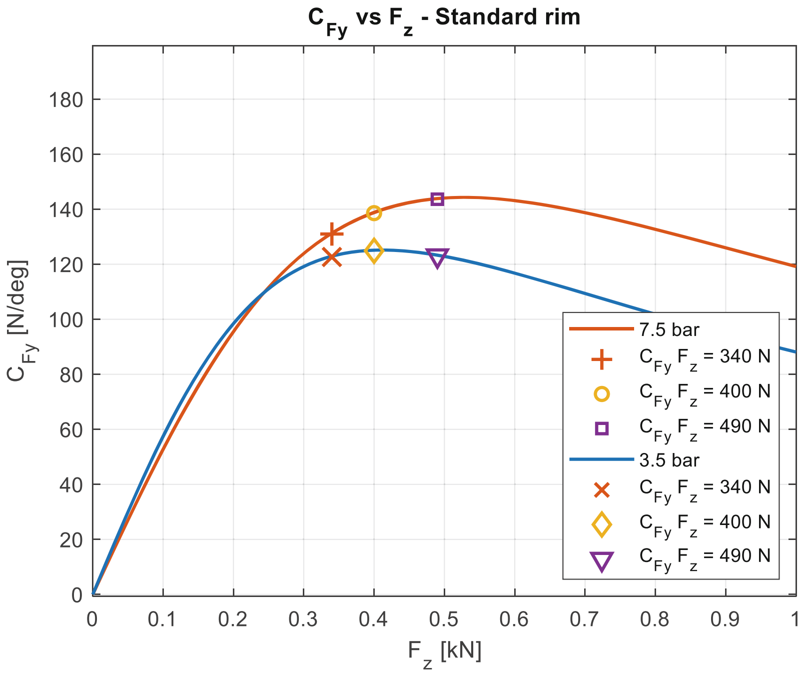


Fig. 4. Cornering stiffness C_{F_y} as function of the vertical load F_z [kN]. The red curve is for inflation pressure of 7.5 bar, the blue one is for 3.5 bar. Tyre was tested on flat track, mounted on aluminum commercial rim [8].

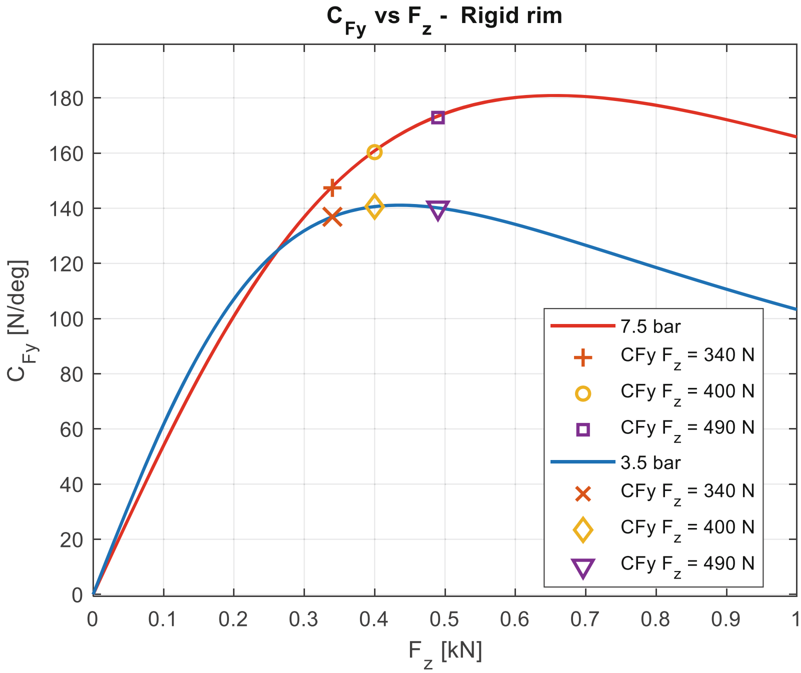


Fig. 5. Cornering stiffness C_{F_y} as function of the vertical load F_Z [kN]. The red curve is for inflation pressure of 7.5 bar, the blue one is for 3.5 bar. Tyre was tested on flat track, mounted on high-stiffness rim [8].

5 Conclusion

This paper presents VeTyT, a test-rig specifically designed for bicycle tyres. An experimental verification of the results was carried out. Given known loads, measurements were performed through VeTyT. We found a systematic error of about 4.5 N for the lateral force, which can be easily compensated in post-processing. As for the self-aligning torque, we found a mean error for the measured torque lower than 1%. The standard deviation was found to be less than 2.5% with respect to the mean value.

The results of an experimental campaign were then presented. A 26 mm wide road racing bicycle tyre mounted on aluminum commercial rim and on high-stiffness rim was tested to derive the cornering stiffness by varying some working parameters (inflation pressure and vertical load). The stiffness of the rim largely affects the lateral characteristics of the tyre. It was found that the use of high-stiffness rim can ensure up to 13% higher cornering stiffness for tyres tested under the same working conditions.

The upgrades made to VeTyT allowed it to fulfill the requirements of standard ISO 9001-15. To our knowledge, VeTyT is first test-rig to measure the lateral characteristics of bicycle tyres in compliance with ISO standards.

References

1. Previati, G., Magnani, G., Mastinu, G.: Analysis of bicycle shimmy and relevant bicycle compliances. In: Proceedings, Bicycle and Motorcycle Dynamics 2019 Symposium on the Dynamics and Control of Single Track Vehicles (2019). https://bmd2019.figshare.com/articles/conference_contribution/Analysis_of_Bicycle_Shimmy_and_Relevant_Bicycle_Compliances/12363707. Accessed 05 Jan 2023
2. Tomiati, N., Colombo, A., Magnani, G.: A nonlinear model of bicycle shimmy. Veh. Syst. Dyn. **57**(3), 315–335 (2019). https://doi.org/10.1080/00423114.2018.1465574
3. Bulsink, V.E., Doria, A., Van De Belt, D., Koopman, B.: The effect of tyre and rider properties on the stability of a bicycle. Adv. Mech. Eng. **7**(12) (2015). https://doi.org/10.1177/1687814015622596
4. Dell'Orto, G., Ballo, F.M., Mastinu, G., Gobbi, M.: Bicycle tyres – development of a new test-rig to measure mechanical characteristics. Measurement **202**, 111813 (2022). https://doi.org/10.1016/j.measurement.2022.111813
5. Dell'Orto, G., Ballo, F.M., Mastinu, G.: Experimental methods to measure the lateral characteristics of bicycle tyres – a review. Veh. Syst. Dyn. **61**, 2738–2760 (2022). https://doi.org/10.1080/00423114.2022.214488
6. Dell'Orto, G., Mastinu, G., Happee, R., Moore, J.K.: Measurement of the lateral characteristics and identification of city and cargo bicycle tyres. Veh. Syst. Dyn. 1–26 (2024). https://doi.org/10.1080/00423114.2024.2338143
7. Dell'Orto, G., Ballo, F.M., Mastinu, G., Gobbi, M., Magnani, G.: Racing bicycle tyres – experimental indoor evaluation of relaxation length. Meccanica **58**, 1523–1537 (2023). https://doi.org/10.1007/s11012-023-01684-z
8. Dell'Orto, G., Ballo, F.M., Mastinu, G., Gobbi, M., Magnani, G.: Racing bicycle tyres – Influence on mechanical characteristics of internal pressure, vertical force, speed and temperature. Eur. J. Mech. A/Solids, **100** (2023). https://doi.org/10.1016/j.euromechsol.2023.105010