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Experimental and numerical investigation on the motorcycle front frame flexibility and its effect on stability

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ABSTRACT

It is well known that front fork flexibility may have a significant effect on motorcycle stability. This work addresses the problem of developing lumped element models of the front fork from experimental results. The front forks of an enduro motorcycle and of a super sport motorcycle are characterized performing static, dynamic and modal tests by means of specific testing equipment. The concept of wheel twisting axis is proposed to characterize static and dynamic deformability of the front fork. Modal analysis results show the presence of two important modes of vibration of the front assembly in the low frequency range: the lateral mode and the longitudinal mode. Different lumped models are discussed and a new model that takes into account information obtained from static and dynamic tests is proposed. Simulations are carried out by means of a multibody code and show the effect of the front assembly deformability on the weave and wobble vibration modes.

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1. Introduction

The study of vehicle stability is a main research topic in the field of single track vehicles [1]. Even if multi-body modeling of motorcycles has experienced much advancement over the last years [2–4] stability still presents some phenomena that require further research and remains one of the most important aspects of the design of safe and powerful vehicles.

Early researchers and motorcycle designers discovered that flexibility of structural components plays an important role in motorcycle dynamics and may alter the stability properties.

The optimal flexibility of a motorcycle remains an open research topic. An established method for flexibility measurement has yet to be defined and nowadays different manufacturers still use quite different measurement approaches.

A recent overview on the effect of flexible components on the motorcycle dynamics is reported in [5].

Most of the time the structural flexibilities are introduced in multibody codes for vehicle dynamics through lumped models, see [2–4,6,7].

The manner in which the position and value of lumped stiffness is identified is rarely addressed in the literature. The first specific work in the topic dates 1983 [8] where the authors carried out both static and dynamic tests to identify the position and value of the front and rear frame lumped stiffness, they analyzed the results of dynamic tests with a single-mode approach, assuming the presence of only one mode of vibration in the frequency range of interest and, in the case of the front fork, assuming the shape of the model as well (a pure bending mode). However, the results between the tests differed significantly and the authors suggested a compromise between static and dynamic results in order to achieve the best agreement with

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experimental findings. No physical explanation on the difference between the two tests is provided. Very little research was carried out and published after this pioneering work.

Reference [9] in 1986 dealt with static tests and in particular torsion stiffness. With reference to a framework of tubes (like some motorcycle chassis) they defined the twist axis as an axis along which no lateral displacement takes place when a torque is applied about it. This definition does not coincide with the wheel twist axis definition adopted in this paper.

Recent experimental test on structural flexibility are reported in [10] (only chassis) and [11–13]. The latter papers employed the method of modal analysis for studying the vibrations of the whole motorcycle. Results have shown the presence of various out-of-plane modes of vibration in the range of frequency below 50 Hz. It is worth remembering that the static compliance is a combination of the modal compliances of various modes of vibration [14,15].

The first aim of the current research is to investigate the number and kind of vibration modes that determine the stiffness and damping properties of current front forks in static and dynamic conditions (note that [9,10] date in the early 1980s). The second objective of the research is to develop modally tuned models of the front fork for investigating the effect of front fork flexibility on vehicle stability.

The work is organized as follows. Section 2 deals with static and dynamic tests carried out on two different front forks: the first is of an enduro motorcycle and the second is of a super-sport motorcycle. Experimental results are analyzed and discussed introducing the concept of wheel twist axis, which is the intersection between the longitudinal plane of symmetry of the unloaded motorcycle and the plane of the front wheel (perpendicular to the spin axis) in loaded condition. When the frequency of excitation increases, the wheel twisting axis moves owing to the excitation of the various fork modes. In Section 3 lumped element models of the front fork are developed on the basis of the modal properties identified in Section 2. Finally, in Section 4 the front fork model is implemented in a multi-body model of a motorcycle and the influence of the stiffness and damping parameters of the fork on motorcycle stability is presented and discussed.

2. Experimental tests

2.1. Experimental equipment and methods

The experimental equipment, known as *"MotoStiffMeter"*, was developed at the University of Padova in order to identify the mechanical properties of typical motorcycle components in static and dynamic conditions.

It consists of a stiff column, a servo-hydraulic actuator, and a system of sensors. The column is equipped with two stiff metal jaws which make it possible to constrain the front fork by locking the steer axis. The actuator is powered by a hydraulic unit, which can produce a static force up to 5000 N and makes it possible to apply dynamic excitation from 0 to 50 Hz.

During the tests, the stem of the actuator is connected to the lower part of the wheel (in correspondence of the contact patch) by means of two hose clamps grasping rigidly both the rim and the tire. A load cell aligned with the actuator axis is used for measuring the force applied by the actuator. The measurement system includes also three laser sensors that are used for measuring the motion of the fork under test. In particular, the three sensors measure the motion of three points of a metal reference plate which is stiffly fixed to the hub of the front fork and parallel to the wheel plane, see Fig. 1.

When a front fork is loaded laterally by forces on the tire/road contact point (or by the actuator during the lab tests) it undergoes both bending and torsion deformations unless the contact point is exactly on the torsion axis, which coincides with the twist axis defined in [9], in this case only bending deflection are observed. The wheel twist axis is introduced for characterizing the whole deformation of the front fork. In more detail Fig. 2 shows that the wheel twist axis is the

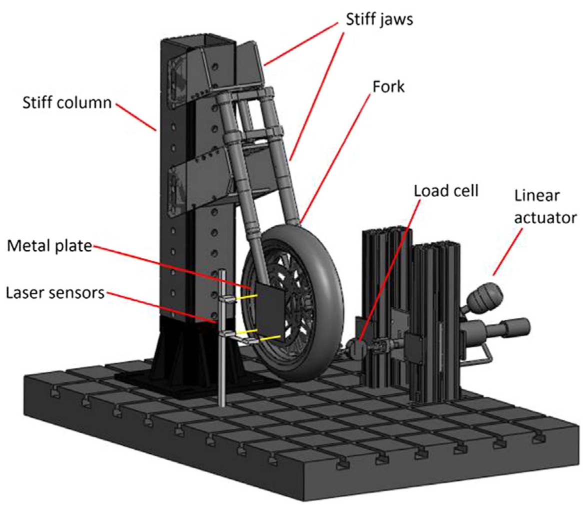

Fig. 1. The "MotoStiffMeter" experimental equipment.

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