RIDER INFLUENCE ON MODAL PROPERTIES OF BICYCLE FRAMES

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Introduction

Over the past few years, bicycles frames have evolved at an important rate. This is in major part due to the introduction of new materials used in frame composition such as aluminium, titanium and reinforced polymers. The use of these materials has been highly motivated by the need to reduce the weight of bicycles. There is also the vibrational aspect to take into account since the majority of the materials used possess low damping values. Particularly, manoeuvrability and comfort should be strongly influenced by the dynamic behaviour of the bicycle.

This work intends to be a first step towards the use of modal analysis to understand the dynamic behaviour of bicycles, and to investigate the influence of the rider and boundary conditions on the modal parameters of road bikes. Two approaches were used to identify the modes of the bicycle. We first looked at the out-of-plane motion using a lateral excitation. Then we studied the in-plane motion using a vertically mounted shaker recreating with more fidelity the road induced excitation. For each approach, modal analysis was performed in the "free-free" condition and with the bicycle standing stationary on the floor with a rider (see figure 1).

Out-of-Plane Motion Analysis

Out-of-plane motion is responsible in preponderance for the manoeuvrability issues since this kind of motion permits the rotation and translation of the two wheels.

Modal analysis was performed using "free-free" boundary condition. All moving components were removed from the bicycle to eliminate potential rattles. A 50-lbs. shaker was linked laterally to the top tube. The structure response was measured by a piezoelectric accelerometer displaced over 63 points on the bicycle. The frequency resolution used on the analyser was 0.5 Hz with a frequency span of 400 Hz.

Figure 1 - Modal testing using lateral excitation with the bicycle standing stationary on the floor.

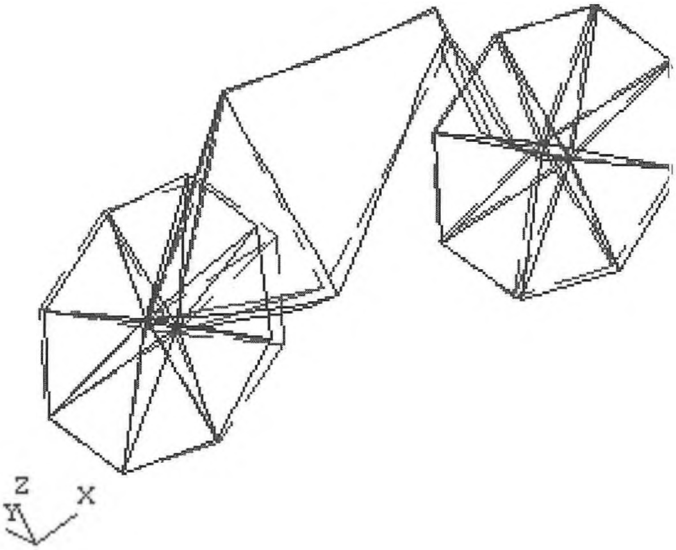

Figure 2 - Critical mode for manoeuvrability in "free-free" condition at 70 Hz. The rear wheel is rotating about the vertical axis.

Clean deformation shapes showing very little damping were obtained. Specific modes were identified as being critical to manoeuvrability since the rear wheel is rotating from left to right (see figure 2). The fundamental frequencies of the identified modes are contained between 26 Hz and 285 Hz.

Afterwards, we conducted the modal analysis with a rider on the bicycle. The curve-fitting process was laborious considering the mode coupling and highly damped peak of the measured FRFs. However, suitable deformation shapes were obtained. Only one mode has proved to be significantly correlated with one of the "free-free" analysis modes found. It is a local mode affecting only the seatstays and probably having a negligible effect on manoeuvrability. The fundamental frequency of this mode went from 175 Hz to 188 Hz when the rider was added.

In-Plane Motion Analysis

The in-plane motion has negligible effect on the manoeuvrability since wheels remain in line when the bicycle is deformed. On the other hand, the vertically oriented road-induced loads tend to animate the in-plane modes, which could be held responsible for the problems of discomfort.

The interaction between the rider and the bicycle has been observed at three different points: the feet, the posterior and the hands. The feet are probably the least significant element because the posterior and the hands mostly support the rider's weight. Moreover, the load applied to the wheels must go through the entire frame to get to the pedals. Conversely, the load applied to the front wheel is transmitted directly to the handlebars by the fork and the load applied to the rear wheel is transmitted directly to the saddle through the seatposts. Only the hands-handlebars interface will be considered in this work since a lot of damping is provided by the saddle, the racing shorts and the buttocks.

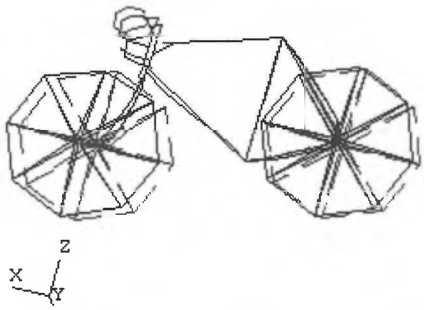

Figure 3 - Critical mode for comfort present respectively at 26 Hz and 22 Hz in "free-free" and "with rider" conditions.

This time, the modal analysis was performed using a vertical excitation on the stem. The frequency span of interest has been reduced to 200 Hz with a frequency resolution of 0.25 Hz. We increased to 82 the number of points on the bicycle to include the stem and the handlebars in the study. The FRFs measurement in the "free-free" condition led us to several interesting deformation shapes, particularly those implicating both the handlebars and the fork at the same time, resulting in more violent modes. We observed that the majority of the recognised modes were affecting locally the handlebars.

Afterwards, modal analysis with a rider on the bicycle was conducted. Most of the modes that were present in the "free-free" condition disappeared. It is mainly the case for the local modes implicating only the handlebars and leaving the fork and the frame static. One mode showed to be highly correlated with one of the modes identified in the "free-free" condition. This mode implicating mostly the fork and the handlebars was found at 26 Hz for the "free-free" condition and at 22 Hz with a rider (see figure 3).

Road Excitation

Since the modal analysis demonstrated that natural modes could be found to a frequency up to 200 Hz, it was interesting to have an idea of the excitation spectrum provided by the road. To do so, an accelerometer was mounted under the handlebars near the stem of a road bicycle. The bicycle was ridded through a typical "moderately rough" road for 10 seconds at a speed of 20 km/h. The experimentation was repeated several times on the same road section and repeatability has been proven.

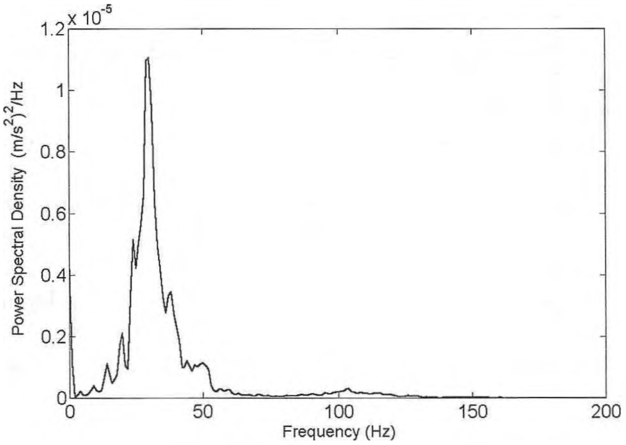

Figure 4 – Power spectral density measured on the handlebars of a road bicycle using a sampling rate of 800 Hz during a 10 s. ride on a moderately damaged surface.

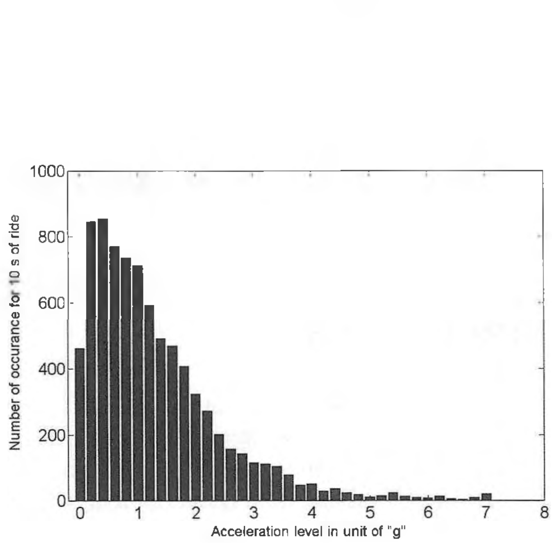

Figure 5 - Number of occurrence of acceleration levels during the 10 s. ride test for each of the 8192 measurement point.

We found a spectral density mostly concentrated in the range of 0-50 Hz (see figure 4). In terms of amplitude, we found that 7g of acceleration was obtained on a moderately damage surface with a speed of 20 km/h. Thus, it would be easily possible that acceleration in excess of 10g would be obtained on a different road or at a different speed. The histogram of figure 5 presents the number of occurrences of specific g levels attained in the 10 second ride test.

Discussion of Results

The out-of-plane analysis showed that the dynamic behaviour of a road bicycle is greatly modified with the interaction of the rider. This is confirming the need to take in consideration the rider interaction during the design process.

Since the road-induced vibrations are mostly contained between 0 Hz and 50 Hz, the modes having fundamental frequency above that level should not be held responsible for problems inherent to manoeuvrability or comfort.

Finally, the in-plane mode implicating the fork and the handlebars found in both "free-free" and "with rider" conditions, at respectively 26 Hz and 22 Hz, should be looked further because the power spectral density recorded in the 10 second ride test is very important in this range of frequency. The concerned mode could play an important role in the comfort of the bicycle.

References

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