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A method for evaluating the vibrational response of racing bicycles wheels under road roughness excitation

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Abstract

The aim of the work was the development of a method for measuring and comparing the vibrational response of different racing rear wheels to the excitation caused by riding on irregular road surfaces. Four different rear wheels were selected for the study. Vertical accelerations at rear wheel axis and at the seatpost were measured during field tests performed while cruising on different road surfaces at different constant speeds. Frequency analysis of acceleration signals was performed using random signal analysis methods. The results show that the ranking between comfort properties of different wheels varies with the road surface roughness and the cruising speed considered.

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Keywords: Racing bicycle; wheels; vibrational response; road excitation; random signal analysis

1. Introduction

The entity of vibrations perceived during road cycling on irregular surfaces is one of the metrics used by cyclists to evaluate comfort properties of the bicycle assembly and its components. Higher vibrations perceived mean an increase of discomfort at arms, legs and lumbar spine which affect the athletic performance of the cyclist. The entity of the vibration transmitted by the bicycle while cruising on irregular road surfaces depends on geometry, mass, inertia and structural characteristics of its components among which the wheels play a main role. Previous studies in this field were focusing mainly on the effects on the comfort of rider's mass [1] during cycling on a treadmill or on the dynamic modeling of the body segments of a cyclist submitted to vibration inputs applied to the cyclist body [2]. In terms of bicycle components, only a few works analyzed the effect of the frame material [3] on the transmission of

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vibration to the cyclist or the damping behavior of bicycle components by modal analysis [4]. To author's knowledge, there are no studies analyzing the vibrational response of bicycle wheels during real cycling conditions. The aim of the work was the development of a method for measuring and comparing the vibrational response of different racing rear wheels to the excitation caused by riding on irregular road surfaces.

2. Materials

Four rear racing wheels (named AR, BR, CR, DR) were selected for the study. All wheels were equipped with the same tubular tire (Continental "Sprinter" 700x23) inflated at 8 bar: wheels were different for material, rim profile, spokes number and disposition as summarized in Table 1.

Table 1. Tested wheels characteristics (* mass including tire and sprockets)

Wheel	Rim profile	Rim material	Hub material	Spokes Nr.	Spokes Pattern	Spokes material	Mass*
AR	Low H 20 mm	Composite	Composite	24	Radial left side	Steel	1320 g
BR	High H 50 mm	Composite	Aluminium	21	2x sprockets side Triplets	Steel	1340 g
CR	Medium H 30 mm	Composite	Composite	24	2x	Composite	1190 g
DR	Medium H 30 mm	Aluminium	Aluminium	21	Triplets	Steel	1420 g

Since humans are sensitive to accelerations [5], vibrations were evaluated in terms of translational acceleration. A standard racing bicycle was therefore equipped with two uni-axial piezoelectric accelerometers model SoMat HLS 1100 (+/- 50 g full scale, 0.3 - 15000 Hz bandpass) positioned with vertical orientation at rear wheel axis and on the seatpost close to the saddle clamping device (Figure 1).

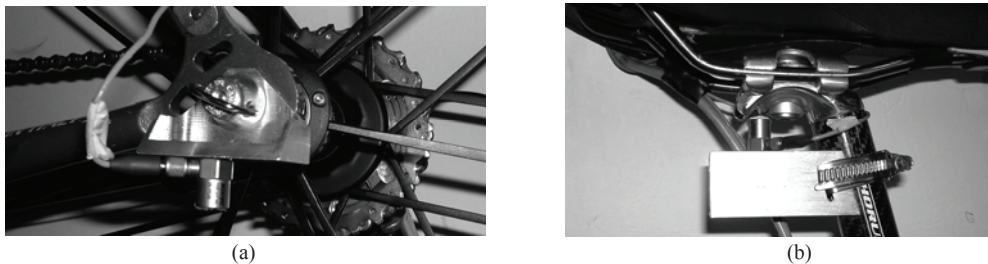


Fig. 1. (a) Uniaxial accelerometer positioned at rear wheel axis; (b) Uniaxial accelerometer positioned close to the seatposts clamping device

The bicycle speed was measured by means of a magnetic sensor positioned on the left fork blade and a magnet fixed on a front wheel's spoke which changes the binary logic level of a digital signal status at every wheel revolution. The magnetic sensor was connected to a digital input channel of the acquisition system, a computed channel was therefore defined in order to convert the frequency of the logic level changes into the bicycle speed. A bike computer was additionally mounted on the bicycle in order to

allow the tester to verify his cruising speed. During field tests, digital and acceleration signals were recorded by means of a SoMat eDAQ Lite acquisition system.

3. Methods

Field tests were performed by cruising with the same instrumented bicycle at three different constant speeds (15, 25, 35 km/h) with each wheel on four types of roads characterized by different pavement surface. The choice of the road was based on the estimation of pavement macrotexture in accordance with the road surface characterization proposed by ISO 13473-1 [6]. The road surfaces chosen were named S1, S2, S3, S4, in order of increasing macrotexture and they represent respectively a smooth asphalt, a draining asphalt, a city pavé and a cobblestones surface.

During the tests, vertical acceleration at rear wheel axis (a_{ar}) and at the seatpost close to the saddle clamping device (a_{sp}) were measured by means of uniaxial accelerometers. Accelerometers channels were sampled at 20 kHz sampling rate, ± 50 g full scale. The frequency analysis of acceleration signals was performed using random signal analysis methods. The PSD (power spectral density) of each acceleration signal was computed by the application of Welch method considering an observation period of 15s length conveniently selected, segmented into 70 sections of equal length, each with 50% overlap and windowed with a Hamming window [7]. Spectra so obtained, which have a resolution of 0.0667 Hz, were weighted by the frequency weighting curve W_k proposed by ISO 2631-1 [6], which expresses the human body sensibility in seated position along the vertical Z axis (Figure 2).

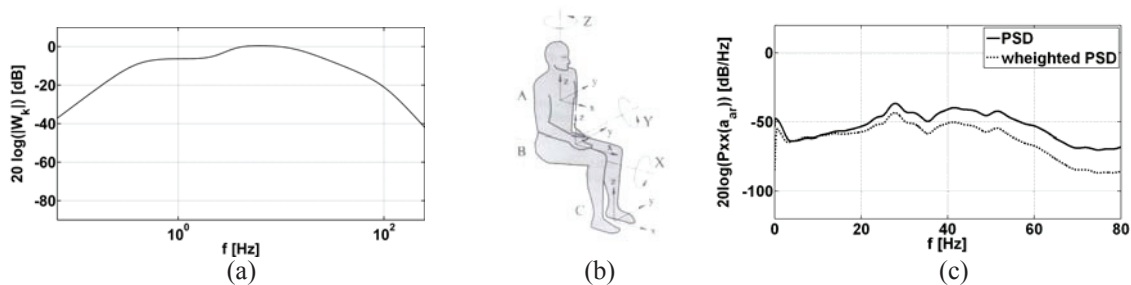


Fig. 2. (a) Frequency weighting curve W_k ; (b) Orthogonal axis of human body in seated position. (c) Effect of weighting curve W_k on spectra shape

The statistical power of each acceleration signal in a chosen frequency range was computed by the integration of the respective PSD. The frequency range considered was [0.5, 80] Hz because in this range vibrations affect human health, wellness and perception [5]. The square root of the statistical power gives the root mean square acceleration a_{RMS} . A comfort index I_C was therefore calculated for each rear wheel at each testing conditions combination (road and speed) as the inverse of the root mean square acceleration computed in the frequency range [0.5, 80] Hz considering weighted PSD.

The acceleration a_{ar} measured at the rear wheel axes was considered as the output of the rear wheel system and as the input of the system represented by the rear part of the bicycle (rear wheel excluded). The transfer function H_{BR} (the subscript BR states for Bicycle's Rear frame) of this system was calculated considering a_{ar} and a_{sp} respectively as the input and the output. The method for the linear system identification based on the analysis of the system response to random inputs which minimize the noise effect of both input and output random signals was used for H_{BR} estimation:

$$H_{BR}(f) = \frac{P_{yy}(f) - \kappa(f)P_{xx}(f) + \sqrt{[\kappa(f)P_{xx}(f) - P_{yy}(f)]^2 + 4|P_{xy}(f)|^2 \kappa(f)}}{2P_{yx}(f)} \quad (1)$$

where $P_{XX}(f)$ and $P_{YY}(f)$ are respectively the PSD of input and output, $P_{XY}(f)$ and $P_{YX}(f)$ are respectively the cross spectral density between input and output and between output and input signals, $\kappa(f)$ is the ratio between spectra magnitude of input and output noise. Since input and output were measured by means of the same measurement system, $\kappa(f)$ was supposed equal to 1.

4. Results and discussion

In the present work, only the preliminary results will be presented with some illustrative examples in accordance with the methodological approach adopted and the limited space available.

Spectra of the rear wheel axle vertical acceleration $P_{xx}(a_{ar})$ obtained after data analysis of tests performed with the same wheel AR, at the same speed on different road surfaces (Figure 3.a) show that the amplitude and the frequency range of spectrum maximum peak, respectively, increase and decrease as road macrotexture increases. Higher cruising speeds determine higher amplitude and lower frequency range of spectrum maximum peak as shown in Figure 3.b. Further investigations will be carried out in order to better understanding this second unexpected behavior.

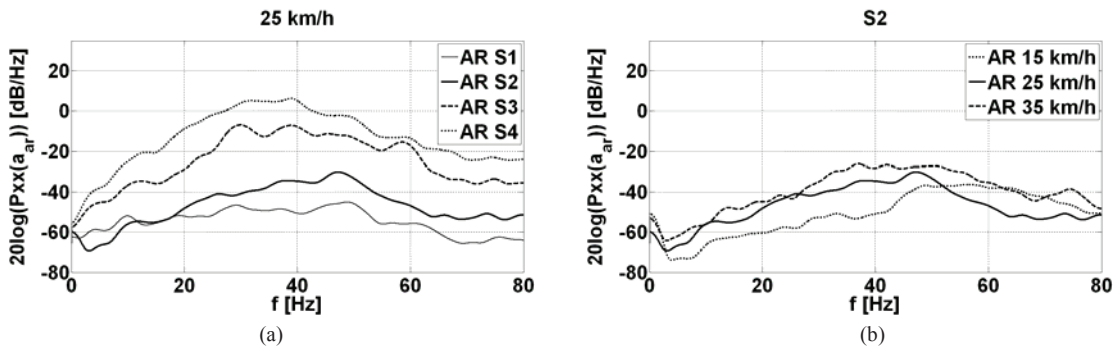


Fig. 3. (a) Spectra of rear axle acceleration obtained from the same wheel AR tested on different road surfaces at the same speed; (b) Spectra of rear axle acceleration obtained from the same wheel AR tested on the same road surfaces A3 at different speeds

Higher differences between $P_{xx}(a_{ar})$ calculated for different wheels were found in spectra computed for smoother road surfaces. This is confirmed by the percentage standard deviation σ^2 between comfort index I_C calculated for the 4 tested wheels in different testing condition: the average values of σ^2 calculated for S1 and S4 are respectively equal to 10.6 % and 3.8 %. This aspect shows that the wheels structural properties have mainly an influence on the transmission of low entity vibrations.

The ranking of wheels vibrational response varied with the road pavement macrotexture and with the cruising speed as can be deduced by a comparison of the weighted spectra and of the comfort index histograms showed in Figure 4.a-f. A more detailed analysis of this aspect can be performed by the comparison between the testing results and the subjective evaluation of the cyclists.

The same bicycle transfer functions were calculated with different wheels, at different speeds and different road surfaces (fig. 4.g-h): this was assumed as a validation of the test method and the overall approach.

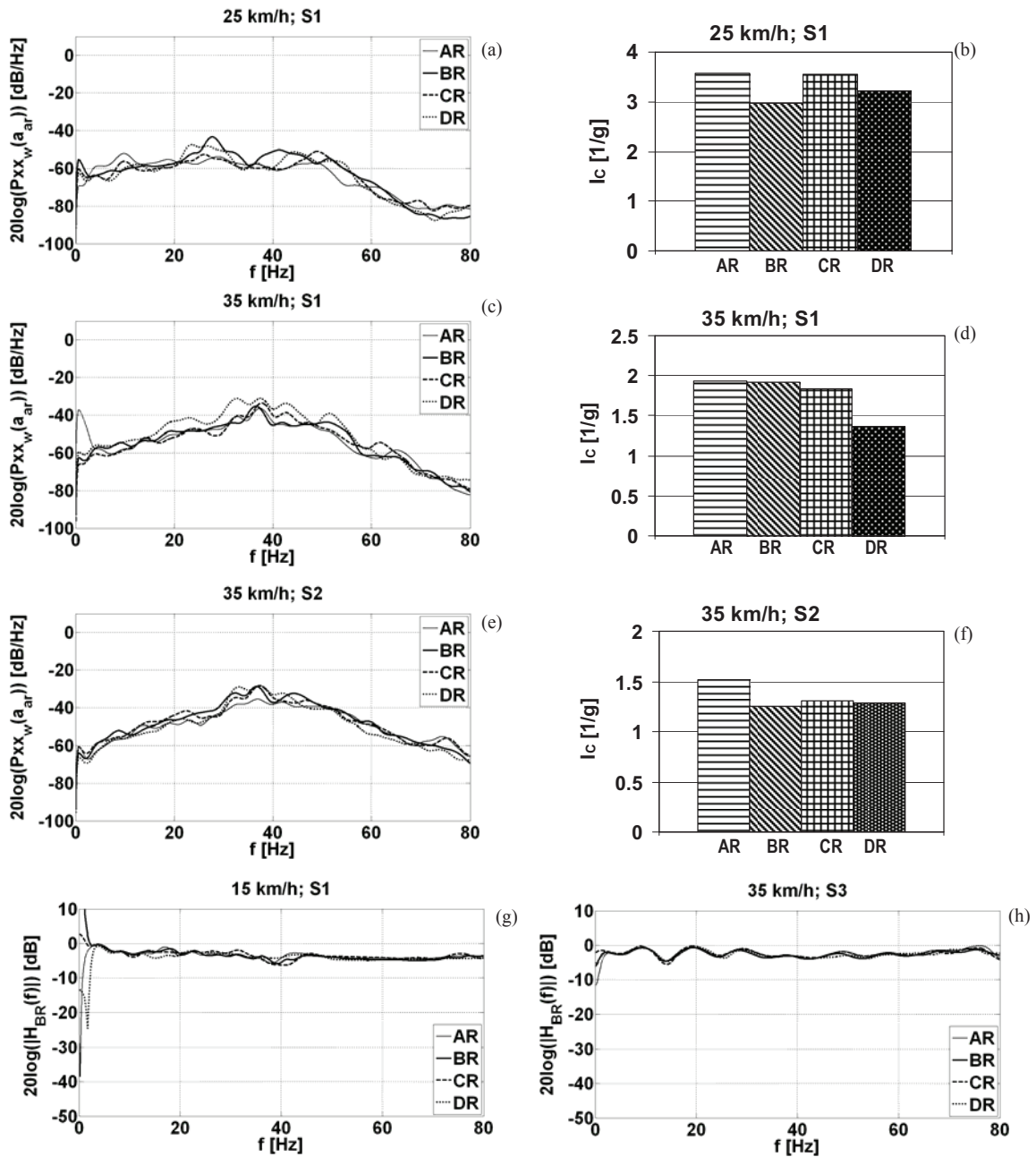


Fig. 4. Weighted spectra of rear axle acceleration and histograms of the relative comfort index calculated for the 4 tested wheels with the following testing condition: 25 km/h and road surface S1 (a, b), 35 km/h and road surface S1 (c, d), 35 km/h and road surface S2 (e, f). Transfer function H_{BR} obtained for 15 km/h and road surface S1 (g), 35 km/h and road surface S3 (h)

5. Conclusions

The present work shows that different wheel models equipped with the same tubular tire inflated at the same pressure can show different vibrational response to road roughness excitations. The ranking between comfort properties of different wheels varies with the road surface and the cruising speed considered. The method developed in the present study can be applied for measuring the vibrational response during real cycling conditions of other bicycles components (such as frame, seatpost, saddle, fork, stem, handlebar..) whose structural behavior can affect the entity of vibrations perceived by the cyclist during cycling on irregular roads. The field tests results can be useful for the development of laboratory vibration tests for testing wheels or other components under real cycling conditions.

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