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Development of a test method for the comparative analysis of bicycle saddle vibration transmissibility

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Abstract

Vibrational comfort is one of the most important parameters evaluated by cyclists during bicycle riding. A method for measuring the saddle vibration transmissibility was developed with the aim of comparing the comfort properties of bicycle saddles without any influence of the full bicycle frame, using a quantitative approach. Three different bicycle saddles were mounted on a stiff seatpost clamped to the extremity of a vertical servohydraulic cylinder: saddles were loaded by a UNI 10814 standard wooden dummy bottom carrying deadweights. After applying a sinusoidal sweep of 0.6mm amplitude to the cylinder, from 1 to 100 Hz, with steps of 2.5 Hz, the application of two piezoelectric accelerometers allowed evaluating the magnitude of the transfer function H between the input acceleration at the cylinder shaft and the output acceleration at the dummy, in the range 1-100 Hz. The three curves of the transfer function magnitude were compared and analyzed in order to introduce a Vibrational Comfort Index and to rank the tested saddles from the engineering quantitative point of view.

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Keywords: Bicycle; saddle; comfort; vibrations; transmissibility

1. Introduction

Comfort is one of the parameters evaluated by cyclists during bicycle riding. It involves multiple aspects such as the position of cyclist on the bicycle, the feelings at the bicycle-body interface and the vibrations perceived by the cyclist during cycling on irregular roads. Focusing on the body-bicycle interface, the pressure distribution in the perineal region can be correlated with a pressure comfort index, whereas the dynamic transmission of vibration to the body can be associated with vibrational discomfort.

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The entity of vibrations perceived by the cyclist during road cycling at a given speed on a specific road surface depends on the geometry of the bicycle and on the mass, inertia and structural characteristics of its main components [1-3]. Being the last bicycle component to be in contact with the body bottom tissues, the saddle is a key element in the enhancement of vibrational comfort, together with cycling shorts and their padding [7]. The modern construction of bicycle saddles expresses the research of manufacturers towards saddle concepts, construction and production technologies that will be able to satisfy the customers requirements of optimal pressure distribution, vibration damping, friction properties and thermal/perspiration qualities, all combined with the minimum cost and mass.

The Quality Function Deployment (QFD) approach can successfully support the development of better products after the identification of a matrix correlating the customers' quality requirements to the products engineering characteristics: the latter are the results of quantitative laboratory tests that shall be available to the product developers for comparing the products.

Aim of this work was to develop an experimental method enabling to measure and compare the saddle vibration transmissibility as an engineering product characteristics. On the basis of former experiences applied to the study of bicycle wheels [4, 5] and of bicycle shorts [7] a new laboratory test method was developed to evaluate the vibration transmissibility of different bicycle saddles models in terms of trend and magnitude of their transfer functions.

2. Materials

2.1 Tested saddles

Three racing bicycle saddles (named A, B, C) were selected for the study. Saddles were different for mass, rail material, shell construction and padding thickness. The three saddles were chosen to come from different manufacturers and to have mass differences not greater than 11% as well as different constructive solutions (posterior splits) or material solutions (gel inserts).

Table 1. Geometric and constructive description of the tested saddles.

Saddle Type	Length [mm]	Width [mm]	Height [mm]	Mass [g]	Rails Material	Shell Material	Padding thickness
Saddle A	272,0	155,0	46,1	210	Titanium alloy	Carbon fiber Short posterior split	Low
Saddle B	260,0	136,0	39,2	196	Vanox alloy	Carbon fiber Long posterior split	Low
Saddle C	280,0	142,0	53,0	220	CroMoly alloy	10% Carbon fibre Central Gel Insert	Medium

2.2 Test bench and instrumentation

A commercial aluminium seatpost was cut at about 50mm from the saddle clamp and was welded to an adaptor aluminium plate enabling to fix it to the 15 kN load cell of a 200 mm stroke vertical MTS 242 servohydraulic cylinder. The vertical axis of the cylinder was therefore intentionally in line with the center of the saddle clamp (see Figure 1.a).

The static vertical load acting on the saddle was applied by a wooden dummy bottom shaped according to UNI 10814, typically used for the durability tests of chairs. The dummy was free of swivel about three axis by means of a ball-socket joint connected to a steel swinging arm hinged horizontally to a fixed structure 1.3 m apart. The dummy was resting on the saddle and it was loaded by a set of dead weights in order to have a total static load of 50 kg on the saddle, as measured by the cylinder load cell (see Figure

1.b). The dummy position of the saddle was initially adjusted after placing a Novel Pliance bike saddle mat over each saddle and measuring the pressure distribution with a cyclist seated on a racing bicycle properly adjusted. The saddles were consistently clamped in the middle of the rails, with null roll & pitch angles of the upper tangent plane with respect to the horizontal, measured with a digital inclinometer. The dummy longitudinal position with respect to the cylinder was adjusted in order to reproduce as much closely as possible the pressure distribution recoded on the saddle with a real cyclist (Figure 1.c).

Accelerations at the support plate (input) and at the dummy bottom upper surface (output) were recorded using two uniaxial piezoelectric accelerometers (SoMat SAPE HLS 1010, +/- 50 g full scale, 0.3 - 15000 Hz bandpass) and a SoMat EDAQ lite at 5 kHz per channel.

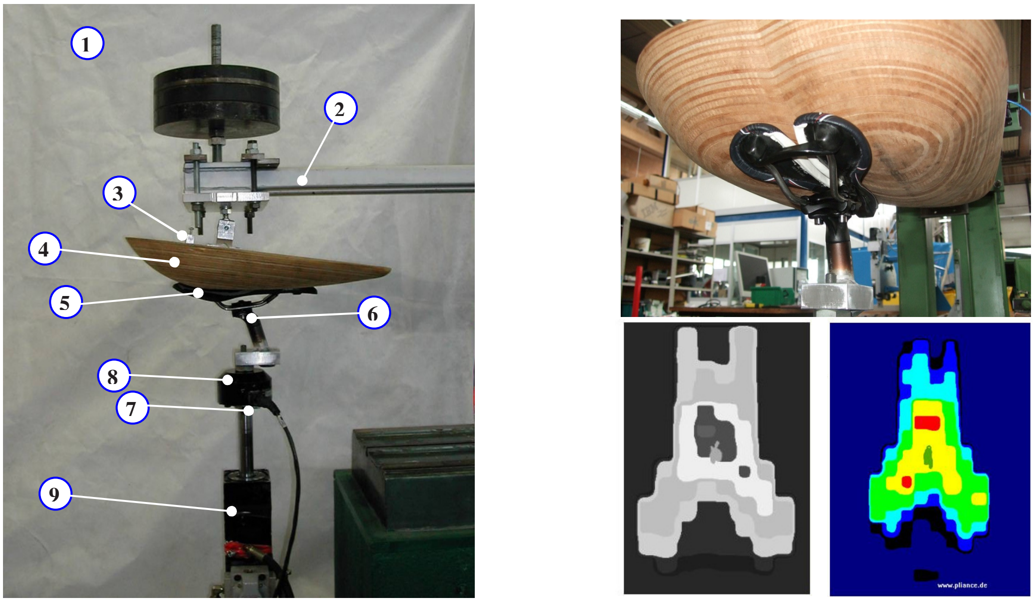

Fig. 1. (a) Experimental test setup: (1) Dead weights of 34.5 kg (2) Swinging arm and ball joint fixation system (3) Output accelerometer (4) Bottom shaped dummy (5) Saddle under test. (6) Dummy Seatpost (7) Input accelerometer (8) Load cell (9) Servohydraulic cylinder. (b) Inferior view of the Dummy-Saddle interface. (c) Comparison between the Dummy Bottom (left) and a cyclist pressure distribution (right) on the same saddle C.

3. Methods

Each saddle was excited by the actuator shaft displacement at constant amplitude (0.6 mm) and frequency ranging from 1 to 100 Hz with discrete intervals of 2.5 Hz after 2.5 Hz.

The actuator shaft acceleration a_{in} and the dummy bottom vertical acceleration a_{out} were respectively the input and the output variables of the dynamic system constituted by the seatpost, the saddle and the dummy. A frequency analysis of both actuator shaft (input) and Dummy (output) acceleration signals was performed for each command block. Discrete Fourier Transform DFT of signals was computed by FFT algorithm. In order to obtain leakage-free spectrums with 0.1 Hz resolution, a total of 50000 samples were considered on each FFT execution, corresponding to an integer number of input sine function periods. The comparison between the amplitude of each input acceleration spectrum $A_{in}(f)$ obtained from the measured signal analysis and the respective theoretical value was performed to verify the correct execution of the related command block.

Transfer function magnitude $|H_k(f)|$ was calculated for each k-th tested saddle, point by point at each excitation frequency f_i. Each transfer function value $|H_k(f_i)|$ was calculated as the ratio between the output spectrum magnitude peak value $|A_{out,k}(f_i)|$, calculated at the excitation frequency, and the corresponding input spectrum magnitude $|A_{in,k}(f_i)|$ as expressed in (1).

$$\left|H_k(f_i)\right| = \frac{\left|A_{out,k}(f_i)\right|}{\left|A_{in,k}(f_i)\right|} \tag{1}$$

Transfer functions obtained from equation (1) were weighted by the frequency weighting curve W_K proposed by ISO 2631-1 [8], which expresses the human body sensibility in seated position along the vertical Z axis (Figure 2.a).

The percent relative difference $\varepsilon_r(f_i)$ between maximum and minimum values of $|H_k(f_i)|$ computed for tested saddles was calculated (3) at each frequency in order to evaluate how differences between vibrational transmissibility of different saddles varied within the considered frequency range.

$$\varepsilon_r(f_i) = \frac{max(|H_k(f_i)|) - min(|H_k(f_i)|)}{max(|H_k(f_i)|)} \cdot 100 \tag{2}$$

A Vibrational Comfort Index, based on the inverse value of the area below the transfer function curve in the 1- F Hz interval, was introduced as a possible engineering characterization of saddles (3). Both the original transfer functions and the ISO weighted transfer functions (Figure 2.b) were used for the index calculation.

$$\mathrm{VCI_F} = \frac{1}{\int_1^F H(f)\,df} \qquad F = 100\mathrm{Hz}\ ,\ 40\mathrm{Kz} \tag{3}$$

From the observation that only in the interval between 1 Hz and 40 Hz the weight function showed values higher than -10 db, the VCI values were calculated over the full range (F = 100 Hz) and the smaller range of higher human sensibility (F = 40 Hz).

4. Results and discussion

The shape of the curves originally obtained for the three saddles resulted to be similar: it was characterized by a main resonance peak around 10-12 Hz, with a transmissibility magnitude around 20 dB, and minor peaks between 25 and 35 Hz (Figure 2.a) where transmissibility magnitude resulted around -10 dB. From 20 Hz onwards, all saddles tended to attenuate vibrations and the transmissibility magnitude were all lower than - 40 dB at 100 Hz. The larger differences between curves appeared around the main peaks and towards 100 Hz. Saddle C showed a transmissibility curve consistently below the other two saddles, in the range 10 Hz-100 Hz: on the contrary, its curve was higher from 2.5 Hz to 10 Hz. Curves of saddle A and B were almost overlapping on all the range, with saddle B showing a smaller transmissibility from 70 to 100 Hz.

The ranking of saddles vibration based on the transmissibility curves resulted to vary with the frequency range considered: after the calculation of the direct Vibrational Comfort Index, spanning over all the 1-100 Hz range, saddle C resulted to have the highest Vibrational Comfort Index and saddle A the lowest. Saddle B had a VCI_{100} that was +4.6% greater than A and saddle C VCI_{100} was +20.8% greater than A. Lower differences were found when the ISO weighted curves (Figure 2.b) were considered for the VCI_{W100} computation: saddle B had a VCI_{W100} that was +7.8% greater than A and saddle C VCI_{W100} was

+10.1% greater than A. An interesting result was that when using the ISO weighted curves, saddle B had a behaviour much closer to saddle C than to saddle A, whereas saddle B was closer to saddle A if the index was calculated on the original unweighted curves. A smaller effect was introduced by the change of interval of integration, from 100 Hz to 40 Hz, as shown in Table 2.

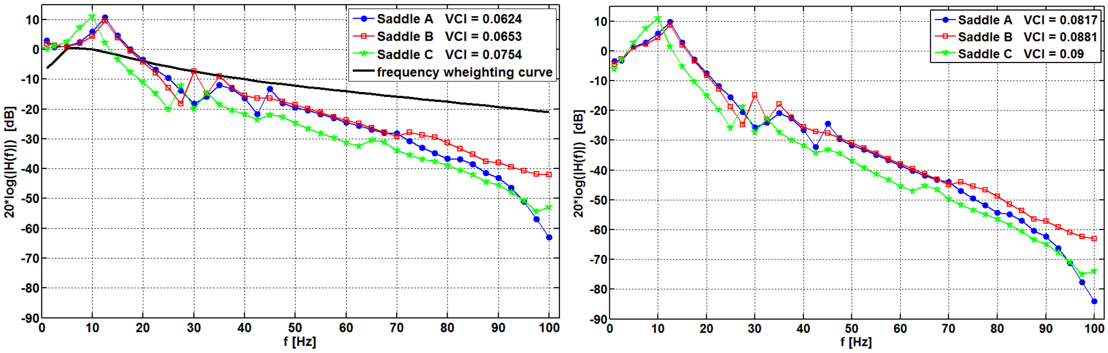

Fig. 2. (a)The resulting curves of the three saddles transfer functions and the frequency weighting curve according to ISO 2631-1; (b) The resulting ISO weighted curves of the three saddles transfer functions.

Table 2. The comparison of Vibrational Comfort Index calculated within 100 Hz or 40 Hz, on the original and ISO weighted transfer functions.

Saddle	**VCI_{100}**	**VCI_{40}**	**VCI_{W100}**	**VCI_{W40}**
A	0.0624	0.0675	0.0817	0.0837
B	0.0653 (+4.6%)	0.0718 (+6.3%)	0.0881 (+7.8%)	0.0890 (+6.3%)
C	0.0754 (+20.8%)	0.0793 (+17.4%)	0.0900 (+10.1%)	0.0913 (+9.0%)

These results suggest the need of performing a subjective evaluation test session in order to definitely correlate the cyclists saddle comfort evaluation results with the engineering results and to identify which VCI_F formulation expresses in the most proper way the cyclist's feelings.

Despite these interesting results testify the ability of the developed test method in quantifying the differences among different saddles from the vibrational point of view, it is also worthy to highlight the limitations of the study.

A first limitation can be recognized in the fact that the test setup is conventional and it involves the use of a wooden dummy that, despite shaped in accordance with an international standard, it has not the elastic, damping and friction properties of a human bottom.

This can be seen as a disadvantage with respect to the aim of characterizing the saddles with an engineering characteristics that should intentionally correlate with the perceived vibrational comfort: however, technically speaking, it was intentionally decided to tests the saddle involving the lowest number of external factors that can influence the tests results and with the most repeatable and reproducible set of test tools. For this reason, the adoption of a more anthropomorphic dummy, with a replica of the pelvis bone geometry and of the human soft tissues by a cast of silicon or other materials was not considered at this stage: previous experiences in this direction regarding the mechanical characterization of seat cushions showed that it can be very difficult to reproduce the dummy consistency throughout the world and that the durability of the dummy surface and bulk properties can be hardly achieved. The second limitation that can be highlighted regards the small number of tested saddles: as usually occurs, the test method was recently developed and is now being tested on a wider number of saddles. The main limitation of the work can be found in the absence, for the moment, of information regarding the perceived comfort behaviour of the saddles, based on customers questionnaires: this will be the first further development of the work, in order to check if the VCI introduced in the work is clearly correlated with a vibrational perceived comfort score of the saddle.

A second interesting development of this study will consist in the correlation of the vibration transmissibility curves with constructive and structural saddle characteristics in order to support the manufacturers' process towards more comfortable products fulfilling the customers' requirements.

5. Conclusions

The works report the experimental method developed for the engineering characterization of bicycle saddles in terms of vibrational transmissibility. The use of a vertical servohydraulic cylinder holding the saddle, the application of a standard bottom shaped dummy loaded on the saddle and the use of two accelerometers allowed to acquire the transmissibility curves of three saddles and to introduce an integral Vibrational Comfort Index (VCI) to rank the saddles. Saddle C resulted to perform as the best saddle, showing a VCI_{100} 20.8% higher than the worst performing saddle, saddle A.

Results of the present work showed that developed method was able to detect different saddle vibration transmissibility and to support a QFD approach to the implementation of innovative and performing bicycle saddles.

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