Operational loads on sport bicycles for possible misuse

Christin Hölzel*, Franz Hoechtl, Veit Senner

Technische Universitaet Muenchen, Dept. Sport Equipment and Materials, Boltzmannstraβe 15, 85747 Garching, Germany

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Abstract

Especially for carbon fiber sport bicycle frames and components the existing standards for fatigue tests don’t satisfy the needs to ensure the athletes safety as numerous failure cases in field show. In order to determine realistic loading pattern for fatigue tests, operational loads for typical usage and reasonable foreseeable misuse have to be known. To determine the occurring operational loads a test bicycle has been developed. For field measurements a standardized test terrain was selected. Additionally special situations were performed to determine operational loads in so-called “possible misuse” situations. Rainflow analysis was carried out for the data mining of typical load cases. Peak forces quantify the possible misuse situations. Analyzing the operational loads related to typical use caused a Rainflowmatrix established for each point of measurement. This data is then used as basis for the development of dynamic fatigue tests on special test benches. According to the peak forces in possible misuse situations additional static tests are suggested to ensure the product safety under extreme use. The enhanced test methods suggested in this paper try to improve existing product tests by taking foreseeable misuse situations into account. The addition of static overload tests to the dynamic test protocol aims to increase the product safety, as existing test protocols don’t consider high static loads. However additional field tests have to be carried out in order to approve the actual results.

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1. Introduction

In cycling especially the combination of cyclic pedal movements and random loads occurring by overcoming an obstacle or overriding a rough surface leads to uncontrolled loads on the bicycle. For this reason it is difficult to assume the loads theoretically. It is also a fact that numerous failure cases occur in field and that the actual test standards for bicycles are not adequate to ensure save products. Therefore it

* Corresponding author. Tel.: +49 8 289 24 505; fax: +49 8 289 16187.
E-mail address: hoelzel@lfe.mw.tum.de.
is important to get to know about the operational loads occurring in field and during possible misuse. There are few studies investigating in loads in cycling [1] [2]. Groß studied occurring loads on mountain bikes [1], Spahl developed strength tests for safety components of bicycles [2]. Both of them investigated loads during riding over cobbled pavement or asphalt only, but they did not attend loads during rough use like mountain bike downhills, drops, etc. Results of these studies could be used for leisure or urban cycling. They might be useless for guaranteeing athletes safety during mountain biking. Nevertheless existing test standards are based on loads occurring during common cycling only. They don’t cover foreseeable misuse situations. Therefore the aim of this study was to show the importance of overloads for testing standards and to integrate static strength tests into fatigue testing methods.

Another disadvantage of the recent studies is that Groß and Spahl just focused their investigation in single components of the bike. This may lead to wrong conclusions about the life cycle of the whole product. Due to this field measurements and foreseeable misuse situations were performed with a special bike (Figure 1) to detect the occurring loads not only within single components but also within the complete product.

![Test bike with global coordinate system](image)

**Fig. 1. Test bike with global coordinate system**

**2. Methods**

To detect the occurring operational loads during mountain biking a special test bike for force measurements was developed. Strain gauges are directly bonded to the components and react corresponding to the elastic movement of the parts. By calibration the voltage at the sensors is matched to the occurring loads at the points of measurement. For the test bicycle strain gauges were attached on the handle bar \( (F_x, F_z) \), the seat tube \( (F_x, F_y, F_z) \), the stem \( (M_x) \) and the pedals \( (F_x, F_y, F_z) \). Ground reaction forces \( (F_x, F_y, F_z) \) are measured with strain gauges in the front wheel hub and with a special lever arm at the back wheel. Information about the current crank angle, needed for transformation of pedal forces from local coordination system into global coordination system, is given by a Hall Effect sensor which differentiates between forward and backward rotation of the crank. Linear displacement transducers at the suspension fork and the shock detect the range of travel. Reed-Relays measure the speed at the back
wheel. The sensor signals from strain gauges are amplified by data acquisition hardware (National Instruments). The hardware, including analog digital conversion, was connected to a mini-pc fixed at the bicycle frame. A data logging software records the sensor signals with a sampling rate of 500Hz. Power supply is realized by rechargeable batteries, which have an operational time of more than one hour. Compared to recent studies testing over longer distances is now possible due to this technical solution [1] [2].

To demonstrate the transfer from measurement data to a test protocol the results for the handle bar are presented. Field measurements and possible misuse situations were performed by a so called maximum load cyclist [3]. For field measurements a standardized test terrain with typical mountain bike up- and downhill passages and trails was selected (2.2km, 70m altitude difference) according to the distribution determined in [4]. To determine operational loads in possible misuse situations jumps from different levels, driving against a wall, rough hitting a road curb and descending down stairs were performed. Detailed information about the situations is given in Table 1 below.

Table 1. Information about the possible misuse situations.

| Possible misuse situations | Comments on the performance | Trials |
|----------------------------|----------------------------|--------|
| Drop jump                  | altitudes: 30cm; 44cm; 54 cm; 71cm | three per altitude |
| Hitting a road curb        | altitude of the curb: 12 cm | three per velocity |
|                            | velocities: 6 km/h; 10 km/h; 15 km/h | |
| Driving against a wall     | velocities: 5 km/h; 7, 5 km/h; 10 km/h | three per velocity |
| Descending down stairs     | different altitudes of the stairs | three |
|                            | different grounds | |

For data mining the recorded voltage signals are transferred to loads by multiplying with the calibration matrices in the first step. The loads from field measurements are then classified with a Rainflow analysis. The resulting Rainflow matrix provides all information on the mean load levels, the amplitude of the loads and the corresponding number of cycles occurring during the test course. The loads are then multiplied with a safety coefficient according to [4] and the number of cycles is increased according to the total life span of a bike which is about 50,000 km, comparing to other investigations [3] [4]. This results in testing time of about 3 days, which is way too expensive and therefore hard to realize. In order to reduce testing time number of cycles is reduced according to Miners rule with a synthetic S-N curve for an aluminium alloy handle bar from [6]. Therefore testing time is reduced to about eight hours. The data analysis results in a multilevel dynamic test procedure equivalent to the load in real life which is an improvement to existing test methods using only one load level for dynamic testing.

The loads out of possible misuse situations were multiplied with a safety coefficient too. Loads were analyzed to get the resulting forces. Afterwards peak forces and force orientation were used to quantify possible misuse situations.

3. Results

The results from Rainflow analysis are shown in Table 2. Mean stress ranges between -207N to 148N in vertical direction with an amplitude between 567 to 70,95N. Overall 20 million cycles would be required if one would directly derive the test protocol from raw data. Reducing cycle time by miners rule
in a damage equivalent way can shorten cycle time to about 100,000. Due to this testing time is reduced to about 8 hours.

Table 2. Fatigue test for the handle bar (direction z).

| Load alternation | Amplitude (N) | Mean stress (N) | Load alternation | Amplitude (N) | Mean stress (N) |
|------------------|---------------|-----------------|------------------|---------------|-----------------|
| 6250             | 354.75        | -135.62         | 31250            | 283.80        | 41.76           |
| 6250             | 496.65        | 6.28            | 87500            | 70.95         | 77.23           |
| 6250             | 567.60        | 41.76           | 93750            | 141.90        | 41.76           |
| 6250             | 141.90        | 112.71          | 137500           | 283.80        | -100.14         |
| 12500            | 141.90        | -171.09         | 156250           | 283.80        | -29.19          |
| 12500            | 425.70        | -100.14         | 225000           | 212.85        | 6.28            |
| 12500            | 354.75        | 6.28            | 393750           | 70.95         | -135.62         |
| 18750            | 425.70        | -29.19          | 650000           | 212.85        | -47.57          |
| 18750            | 212.85        | 77.23           | 725000           | 141.90        | -100.14         |
| 25000            | 70.95         | -206.57         | 2093750          | 70.95         | 6.28            |
| 25000            | 354.75        | -47.57          | 2562500          | 141.90        | -29.19          |
| 25000            | 70.95         | 148.18          | 12881250         | 70.95         | -47.57          |
| 31250            | 212.85        | -135.62         |                  |               |                 |

However this test procedure corresponds to the loads in normal cycling only. To account to possible misuse situations the peak forces of these situations are evaluated according to the direction of the force and its magnitude. Forces range between 300 N and 1000 N at the handle bar. Differences are caused by different situations performed. Highest load occurred while riding against a wall. Lowest load was detected during riding up stairs. Directions of the forces are shown in Figure 2a.

Static overload tests are derived considering a safety factor of 1.5 on the loads. Three main directions (red arrows in Figure 2(a)) were identified and chosen for static strength tests. The tests are carried out on a special test bench for stem and handle bar combinations (Figure 2(b)).

It consists of two pneumatic actuators which apply vertical forces to the handle bar up to 2kN (Figure 2(b), Number 1). The clamping positions at the handle bars are in the middle of the handholds. The handle bar can be rotated to realize the different force directions (Fig 2(b), Number 2). The actuators are controlled with intelligent Syscon-Controllers which assure adequate force characteristics.
4. Discussion

To detect occurring operational loads field measurements were performed during mountain biking on typical tracks. In order to show the procedure how to derive test protocols from the recorded data, Rainflow analysis was carried out considering an additional safety factor. Comparison of the results with former investigations [4] shows good agreement of the load levels and their occurrences. Analyzed data
was used as a basis for the development of dynamic fatigue tests on special test benches. Shortening the number of cycles in a damage equivalent way reduced testing time from several days to eight hours.

To enhance the test protocol by considering possible misuse situations field tests were carried out. Realistic misuse situations were defined and the recorded data was analyzed concerning the peak forces and their directions. Out of this static strength tests were added additionally to the dynamic test protocol.

Results for common use show much lower loads compared to the possible misuse situations. The forces at the handle bar, while for example performing a drop jump, can be twice as big then during normal biking. Due to this the force difference between proper use and possible misuse is high. Occurring loads during field tests range between 400 and 450 N whereas the highest load during possible misuse is around 1000N for the handle bar. This fact shows that additional static strength tests are important for realistic product testing. Most of the actual testing standards do not include static strength tests additionally to the fatigue tests, for example the EN testing standard for bicycles [5]. Due to this athletes safety cannot be ensured.

Summing up field measurements are at a very early stage at the moment. Therefore additional data needs to be collected and analyzed. This paper exemplary shows data analysis procedure for the handle bar, beginning with field data collection resulting in product tests. Furthermore a suggestion for enhanced product testing caused by the addition of static strength tests to dynamic fatigue testing is given. The occurring load levels show, that static peak loads outrange dynamic peak loads by factor two. For this reason existing dynamic test methods don’t account for typical misuse situations. The generated lab testing methods for bicycle frames and components might be an enhancement for current test standards due to the integration of the loads occurring in possible misuse situations.

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