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Development of instrumented downhill bicycle components for field data collection

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Abstract

A downhill bicycle was equipped with strain gauge bridges at the most significant safety components, stroke sensors at the suspensions and accelerometers at the front axle. A set of 7 channels was applied on the frame, 4 channels were applied to the rear swing arm, 6 channels to the front fork, 2 channels to the front and rear brakes and a customized load cell was connected to the rear damper. Each channel was calibrated during static laboratory tests and the calibration constants or matrices were used to convert the measured signals into functional loads applied to the components. Tests were performed involving an expert downhill racer on a competition track.
The peak values collected during the study would allow for the definition of static overload tests on the bicycle safety components; the time histories collected in the field will allow evaluating the field loads spectra to be used in the fatigue life prediction of the components and defining the standard fatigue tests to verify the minimum required fatigue strength of the most important components of such an extreme sport discipline.

Keywords: Downhill bicycle; instrumented components; field tests

1. Introduction

The development of an acrobatic discipline such as downhill cycling has involved the increase of frame and components manufacturers and the growth of the number of users addressing this extreme discipline either for competition or for amateur use. Despite its diffusion and the fact that downhill can be classified

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as an extreme sport, no safety regulations have yet been published by national or international standard institutes regarding the static, impact and fatigue strength requirements on this type of bicycle, as published for other categories such as racing or mountain bikes [1-3]. Aim of the work was the preparation of a fully instrumented bicycle for the field data collection of load spectra acting on the most critical components during typical downhill courses, on the basis of former experiences on MTB bicycle components [4-6].

2. Materials and Methods

2.1. Bicycle description

The downhill bicycle used in the study is shown in Figure 1.a. The frame was an Easton 7005 aluminum alloy triangular frame, model CRAB, 4.5 kg mass, manufactured by MDE Bikes (To, IT): it presented a rear swing arm hinged at the down tube and supported by a rear dumper Marzocchi ROCO RC parallel to the horizontal tube, connected to the upper portion of the down tube. The front fork was a Bomber 888 RC2X double clamp Marzocchi fork, nominal stroke 200 mm, wheel axle diameter 20 mm (Figure 1.b). Brakes were a pair of Formula Oro 24 K with 200 mm disks (Figure 1.c); two DEEMAX wheels from Mavic were used together with LOBO MAS LOCO 2.5 tires. The crankset, the handlebar and the seat post were from Truvativ, model Husselfelt, the transmission and chain were from SRAM, the saddle was a Fizik Freek. The total mass of the fully equipped bicycle was 20 kg .

(a) (b) (c)

Fig. 1. (a) Overall view of the downhill bicycle; (b) View of the Marzocchi front fork with indication of Normal axis X and parallel axis Z adopted with accelerometers; (c) Details of the instrumented front brake (upper) and of the rear damper load cell (lower)

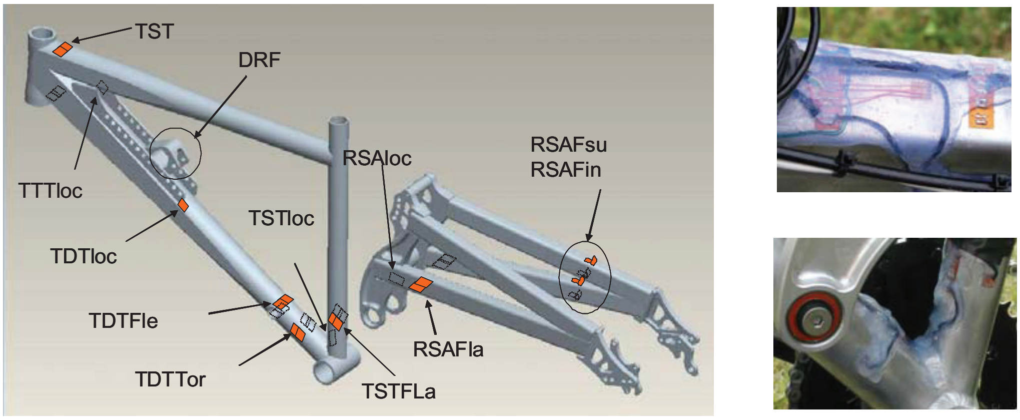
2.2. Instrumented components

The aim of the project was to collect functional load histories useful for the development of static, fatigue and impact tests: it was therefore planned to prepare a downhill bicycle with the highest number of instrumented components and with the greatest completeness of measured load components. In the present work, the first part of the project will be reported, including all components apart from the handlebar and the front wheel axle that were developed and used in a second stage of the project.

The frame, the rear swing arm, the front fork, the rear dumper and the brakes were instrumented with strain gauge bridges, calibrated during static laboratory tests and used to collect field data. All components apart from the rear damper were directly used as measuring components due to their slim design and to the possibility of decoupling the load components using appropriate disposition of strain gauges. The full list of the measuring channels is reported in Table 1.

Table 1. List of the measuring channels developed on the instrumented components of the downhill bicycle

Ch. Nr.	Name	Description	Units	Type
1	FFstro	Front Fork Stroke	mm	Lin. Pot.
2	FTFFL	Fork Tube Longitudinal Bending Left	MPa	SG 4/4
3	FTFFR	Fork Tube Longitudinal Bending Right	MPa	SG 4/4
4	FTFLat	Fork Tube Lateral Bending	MPa	SG 4/4
5	FSFF	Fork Stem Longitudinal Bending	MPa	SG 4/4
6	FSFLat	Fork Stem Lateral Bending	MPa	SG 4/4
7	FST	Fork Stem Torsion	MPa	SG 4/4
8	FB	Front Brake Force	N	SG 4/4
9	RB	Rear Brake Force	N	SG 4/4
10	FWaccX	Front Wheel Normal Acceleration	g	SG accel.
11	FWaccZ	Front Wheel Parallel Acceleration	g	SG accel.
12	DRF	Damper Rear Force	N	SG 4/4
13	DRstro	Damper Rear Stroke	mm	Lin. Pot.
14	TST	Frame, Steering Tube Bending	MPa	SG 4/4
15	TTTloc	Frame, Gusset Welding Local Tension	MPa	SG 1/4
16	TDTloc	Frame, Down Tube Local Tension	MPa	SG 1/4
17	TDTFle	Frame, Down Tube Bending	MPa	SG 4/4
18	TDTTor	Frame, Down Tube Torsion	MPa	SG 4/4
19	TSTFLa	Frame, Seat Tube Lateral Bending	MPa	SG 4/4
20	TSTLoc	Frame, Seat Tube Local Tension	MPa	SG 1/4
21	RSAFLa	Rear Swing Arm, Lateral Bending	MPa	SG 4/4
22	RSAloc	Rear Swing Arm, Local Tension	MPa	SG 1/4
23	RSAFsu	Rear Swing Arm, Axial Load Upper Rod	MPa	SG 4/4
24	RSAFin	Rear Swing Arm, Axial Load Lower Rod	MPa	SG 4/4



(a) (b)

Fig. 2. (a) Denomination and disposition of strain gauge bridges applied to the main frame and the rear swing arm; (b) Details of the strain gauges applied at channel TST (upper) and at the bottom bracket joint (lower)

The front fork channels were applied at the Fork Stem and at the Fork Tubes, with the aim of collecting the actions supported by this structural and safety components in most directions. The fork stem was equipped with three full-bridges strain gages: together with a torsion full bridge (gauges disposed at +/- 45° to the steering tube), the two bending full bridges were applied close to the bottom bearing in the longitudinal and transverse planes (gauges placed 2 by 2, symmetrically at the two sides of the tube). Longitudinal bending bridges at the fork tubes were applied similarly: lateral bending was obtained by connecting as a full bridge two couples of gauges from each tube.

The frame and the rear swing arm were the components studied in highest detail, as requested by the frame manufacturer: nominal stress components due to bending and torsion moments or to axial loads were measured with full bridges, local stress values at the weld toe of critical locations such as the reinforce gussets at the steering tube, the bottom bracket joint and the swing arm main joint were measured with small quarter-bridge type strain gauges. The disposition of such bridges and details of the gauge application to the frame are reported in Figure 2: bending and torsion bridges were obtained similarly to the fork bending and torsion bridges, the axial load components were measured with full bridge axial channels presenting two gauges parallel and two gauges transverse to the rod axis.

A particular solution was adopted for measuring the force transferred by the rear damper: the original fixture connecting the damper ball joint with the down tube gusset was substituted by a specially designed hollow block as shown in Figure 1.c. A full bridge was applied to the outer and inner faces of the curved portion of the fixture that was eventually calibrated as a load cell by means of a hydraulic actuator.

Front and rear brakes were instrumented by the application of eight small strain gauges connected as two full wheatstone bridges to be insensitive to temperature changes: the calliper brackets were partially machined to obtain more deformable components and higher sensitivity for the channel.

Additional commercial sensors were used for measuring the stroke of the front and rear suspensions (two RDP linear potentiometers) and two acceleration components at the front wheel axis (two 25 g accelerometers, 200 Hz band pass). The stroke signals were zeroed at the suspensions fully extended positions (lifted bicycle) and had positive increasing values when suspensions were closing; accelerations were taken in the direction parallel to the steering axis, positive upwards (Figure 1.b, Z-axis) and normal to the steering axis, positive forward (Figure 1.b, X-axis).

2.3. Test Methods

Several laboratory tests were performed to calibrate the fork channels, the frame channels, the rear swing arm and the brake channels: after defining proper bench fixtures to support the components undergoing calibration, a set of known loads was applied to the instrumented component and the bridge outputs were collected to obtain the channel calibration constants. In the case of possible mutual influence of different planes of loads, matrix calculations were used, such as in the case of the front fork (Figure 3.a) and the frame.

(a) (b) (c)

Fig. 3. (a) Calibration tests of the complete fork; (b) Fully equipped bicycle and rider during the tests; (c) Rider during the most demanding portion of the track with large steady stones

Field tests were performed during several sessions on a former Italian DH championship race track of 2.6 km length, 400 m drop, presenting several types of surfaces (Figure 3.c) and jumps: a skilled amateur rider of 73 kg mass, very familiar with the track, was involved in the tests.

Data were collected by means of a Somat 2300 data acquisition system, at 1 kHz sampling rate, placed on a backpack with the supply battery (total mass 8 kg): signal cables from the front fork reached the unit after being wrapped to the left arm of the rider (Figure 3b).

3. Results and Discussion

The results of the field tests as collected at some of the front fork channels are reported in Figure 4 as an example of the collected data: the run was divided in two parts by a rider stop after about 250 secs, corresponding with a track change. From the analysis of Figure 4 some observation may arise such as the differences between left and right tube bending (due to the presence of the disk brake on the left) or the overall symmetry of the normal acceleration signal FWaccX around the zero value.

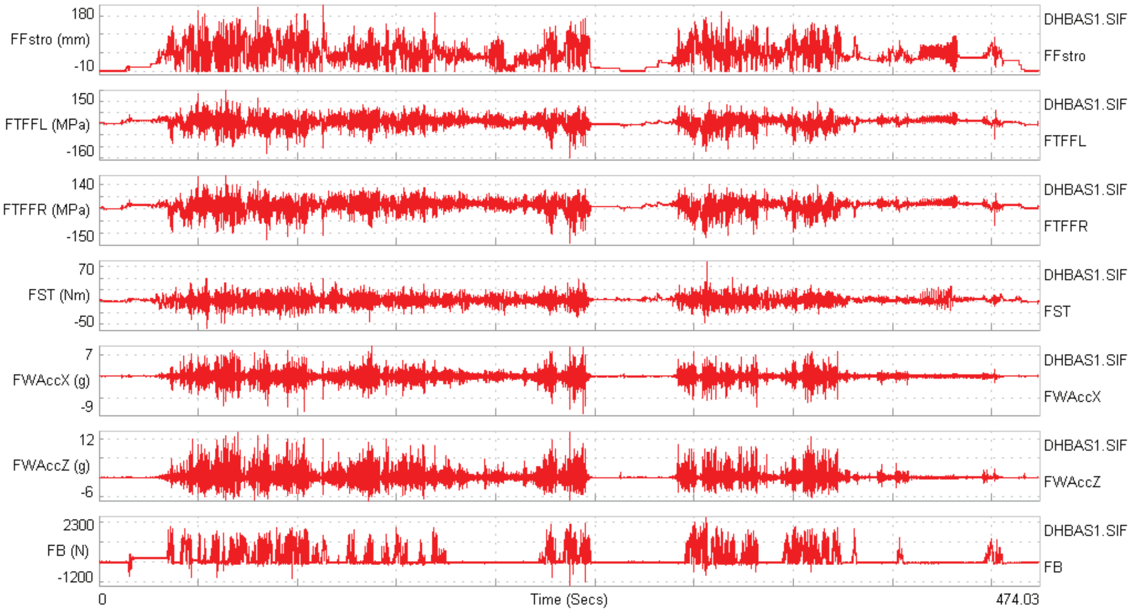


Fig. 4. Example of collected data on seven channels on the front fork

Table 2. List of the Max/Min values recorded for some of the channels applied to the downhill bicycle

Ch. Nr.	Name	Description	Units	Max	Min
1	FFstro	Front Fork Stroke	mm	179.7	-6
2	FTFFL	Fork Tube Longitudinal Bending Left	MPa	148	-158
3	FTFFR	Fork Tube Longitudinal Bending Right	MPa	139	-149
7	FST	Fork Stem Torsion	MPa	66	-45
8	FB	Front Brake Force	N	2280	-1100
10	FWaccX	Front Wheel Normal Acceleration	g	6.95	-7.97
11	FWaccZ	Front Wheel Parallel Acceleration	g	11.77	-5.97
12	DRF	Dumper Rear Force	N	7360	-1211
13	DRstro	Dumper Rear Stroke	mm	63.7	-1

The maximum and minimum values of some of the measured channels are reported in Table 2. As it can be seen, the rearward bending values of fork tubes (negative) were slightly more intense than the forward ones.

High values of stem torque were recorded while running at medium speed across large steady stones (Figure 3.c): these values were very close to the minimum requested values for MTB forks, thus suggesting an increase of the requirements in a possible downhill standard.

Braking forces were quite high in the positive (forward) direction, with unexpectedly frequent negative peaks related to the dynamics of braking on rocky surfaces.

Acceleration peak values were symmetric about zero in the normal direction, but biased towards the positive (upward) values in the parallel direction.

The synchronous acquisition of loads acting on the fork, the rear swing arm and the rear damper allowed to introduce the load components on a FEM model of the bicycle frame and to validate the FEM model outputs by means of the experimental stress/strain values collected at the strain gauge applied to the frame on specified locations. Moreover, the stress peak and range values will enable to drive a set of load actuators applied to the instrumented bicycle to reproduce the field stress ranges by means of known actuator loads: this will allow defining of a fatigue test method suitable for reproducing the damage coming from the field and for validating the frame fatigue resistance.

4. Conclusions

The work presents the approach adopted in the preparation of an instrumented downhill bicycle used for the collection of realistic field data to be used for the component design and safety testing. A total number of 20 strain gauge channels were applied to the bicycle components, together with two suspension stroke sensors and two accelerometers at the front axle. The strain gauge disposition and the adopted bridge connection are described, together with maximum and minimum values recorded for the front fork channels and the rear damper as a support to downhill component design and testing.

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