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Embedded Fibre Optic Sensors for Structural Analysis of MTB Bicycle Frame

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Abstract. The article is focused on structural analysis of the composite bicycle frame. Head tube joints were equipped with embedded optical FBG sensors. Frame was tested according to ISO test cases. Additional structural strength laboratory tests were done to evaluate range of limit case strain ranges. Digital image correlation method was used for the strain distribution evaluation in the head tube area. It was found that bicycle frame was designed with sufficient safety reserve.

Introduction

Bicycle frames made from Carbon Fibre Reinforced Polymers (CFRP) are widely commercially available nowadays. Besides prepreg moulding technology the composite wound tube technology is the most common bicycle frame manufacturing method. It allows to design the frame to customer's needs. In general, the most problematic places of the bicycle frame construction based on wound tubes are joints of individual tubes. Common way of joining the tubes using the glued sleeve joints has its performance and visual limits. So research was focused on improvement of joints made using the hand lay-up lamination technology. Structural strain analysis is an integral part of such research. However, commonly used electric strain gauges method has crucial disadvantage. Strain gauge cannot be embedded inside the composite lay-up or adhesive joint, so only a surface strain can be measured. This could be insufficient in a case of need of strain analysis of the place with complicated geometry. Structural analysis of the specific layers of composite lay-up or joints can be performed using the Fibre Bragg Grating (FBG) sensors measurement technology, because FBGs are small enough to be placed between the particular filaments.

Experimental Methods

Two strain analysis methods were used. Embedded FBG sensors were used for the local strain analysis. Digital Image Correlation (DIC) method was used to examine complex mechanical strain distribution in the head tube area.

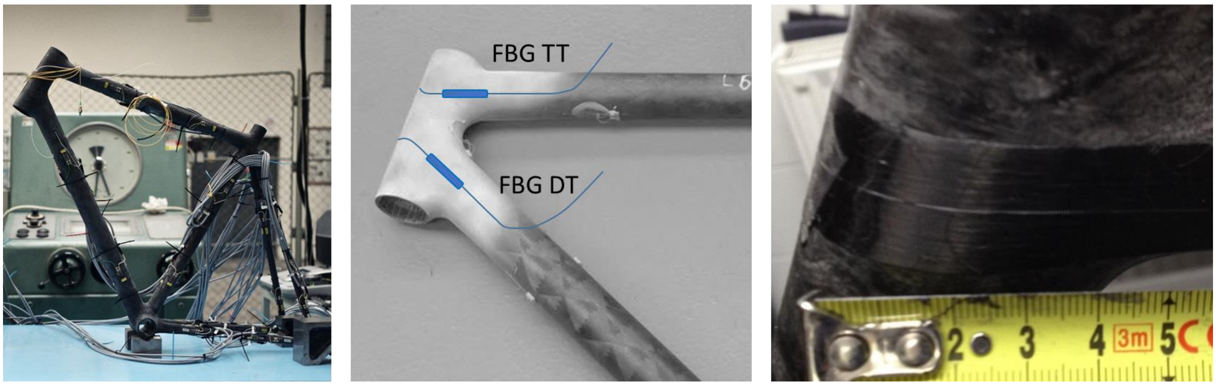

Fig. 1: Bicycle frame with embedded and surface sensors installation (left); locations of FBG sensors (blue marking, centre); detail of FBG sensor placement during the hand lamination (right)

Structural FBG sensors. Bicycle frame was instrumented with surface-mounted strain gauges and structural FBG sensors (Fig. 1 left). Optical fibres were embedded into the joint of the top tube (FBG TT) with head tube and into the joint of down tube (FBG DT) with head tube (Fig. 1 centre), directly between the unidirectional carbon filament layers (Fig. 1 right). These places are critical for transfer of horizontal forces from the safety point of view. Two ORMOCER® coated optical fibres with outer diameter of 0.2 mm, instrumented with one FBG sensor per fibre (with central wavelength of 1550 nm) were used. Surface routing of the fibres was protected using the plastic tubes. Mechanical strain indicated by the FBG sensors was measured and evaluated using the Safibra FBGuard optical interrogation system.

Digital Image Correlation. 3D DIC method was used to measure surface strain field in the head tube area. Dantec Dynamics Q400 commercial DIC system was equipped with two 16 Mpix digital cameras. Istra 4D software was used for data evaluation. To compare measurement methods, average longitudinal strain was evaluated along the line representing FBG sensor routing in its sensing area.

Experimental Procedure

In the first phase of the experiments, the bicycle frame was tested in cooperation with the EFBE Prüftechnik GmbH. The aim was to get a comprehensive idea of the behaviour of the bike frame in the ISO defined load cases. This was followed by the ergometer test and the laboratory testing up to structural failure to examine the structural strength of the frame [1].

Standardized Load Cases. Set of frame loading procedures was based on ISO 4210-6 [2] bicycle safety standard supplemented by specific load cases: 1. pedal forces; 2. horizontal forces (front/back load through the fork); 3. vertical forces (loading through the seat tube); 4. bottom bracket stiffness; 5. head tube torsion stiffness (measured between the front and rear wheel plane, see Fig. 2 left). Mechanical strain indicated along the FBG sensor axis was measured (see Fig. 2 right for results of test no. 5) and was then used to evaluate local stresses for each load case.

Ergometer test. The frame was fitted with components and loaded by pedal forces on an ergometer. The ergometer is an exercise machine that loads the rear wheel and creates pedalling resistance. The rider performed a series of sprints in order to obtain the maximum load from pedalling.

Structural Strength Tests. The work was focused on the most critical load case in terms of a rider safety, the horizontal forces test. Forces acting on the fork during jump, riding through a pothole or a frontal impact were simulated using the hydraulic actuator. Experimental setup and an example of DIC method evaluation is in the Fig. 3. Pushing load case was examined because of the highest expected deformations.

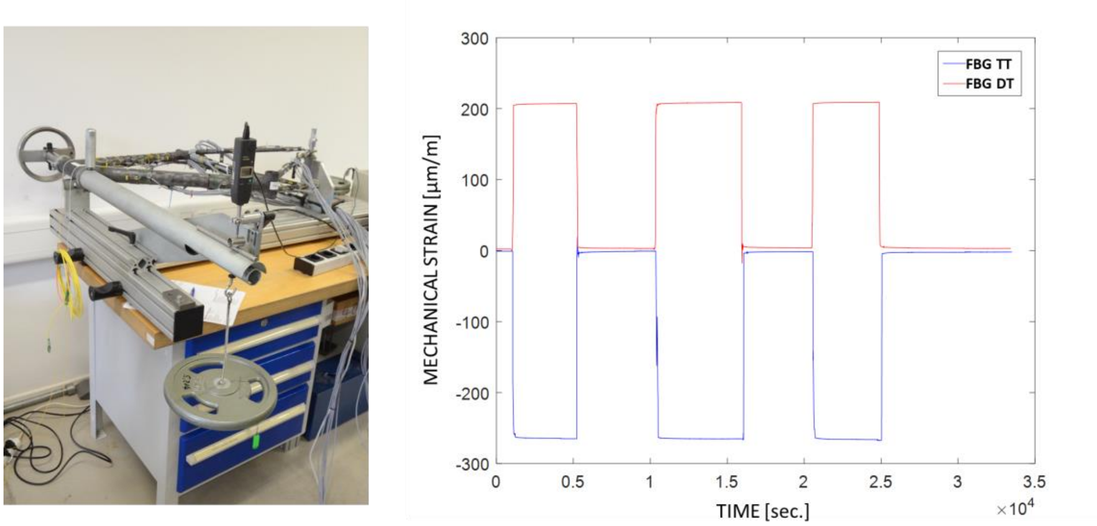

Fig. 2: Head tube torsion test set-up (left), evolution of mechanical strain measured by FBG sensors over time (right)

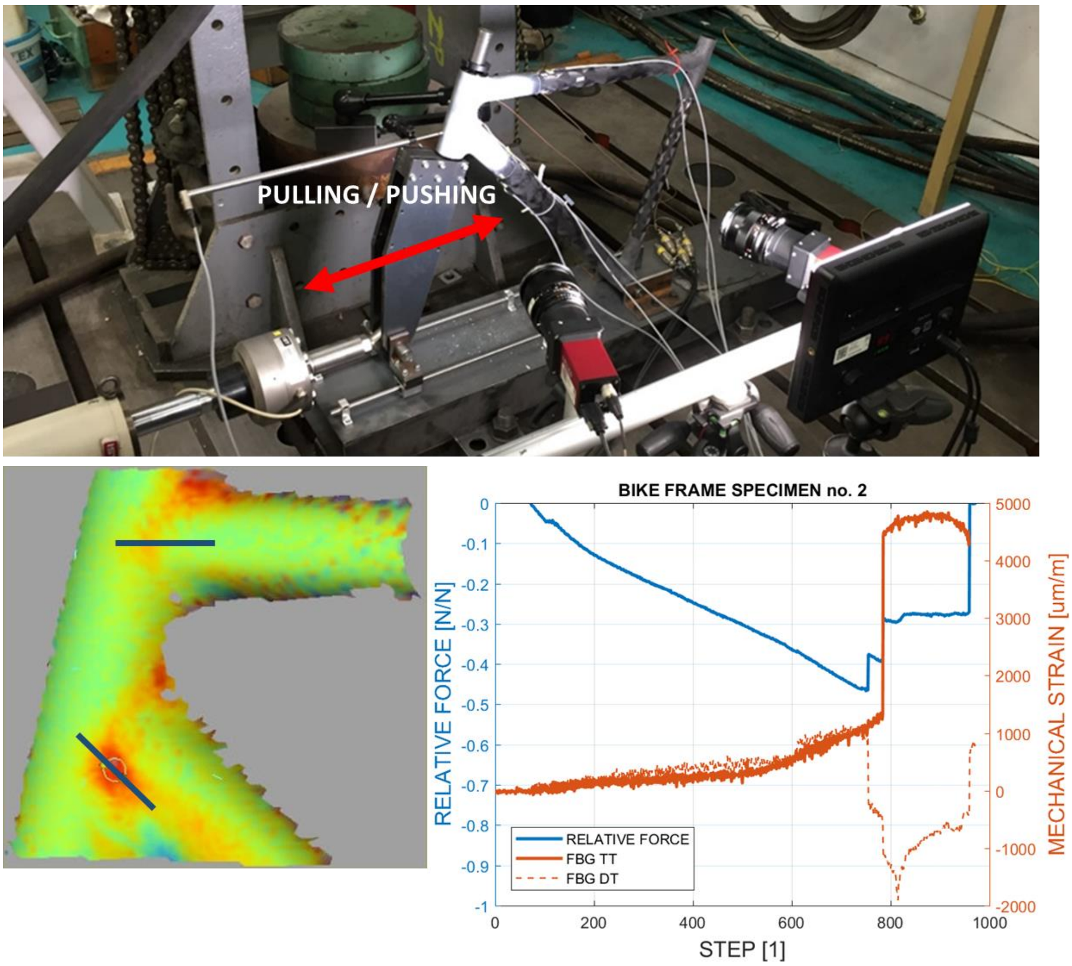

Fig. 3: Experimental setup for horizontal forces test (top), definition of FBG sensors locations for DIC method evaluation (bottom left), mechanical strain in the FBG TT and FBG DT sensors locations (bottom right)

Results and Discussion

Experimental results are presented in the Table 1. Maximum strain values for individual load cases were evaluated separately for the FBG DT and FBG TT areas. It can be seen that the highest strain values are resulting from pedal forces. Regarding the tests feasible in the laboratory and usable for the verification of finite element models, the highest strain values were found in the case of horizontal forces. Down tube is apparently the main load bearing bike frame member. The first five rows represent ISO defined test cases. Compared to the maximum strain values evaluated from strength test it is obvious that the tested bike frame design has sufficient safety reserve.

Table 1: Summary of experimental results

	FBG DT [μm/m]	FBG TT [μm/m]	comments
pedal forces	735 / -595	575 / 614	loading from left side / right side
horizontal forces	349 / -357	133 / -177	pulling / pushing
vertical forces	12	-14	
bottom bracket stiffness	-38	41	
head tube torsion stiffness	-267	209	
ergometer test	963 / -689	627 / -766	loading from left side / right side
structural strength test (data evaluated using DIC method)	-1 800 ÷ 940	-10 ÷ 1 700	range of maximum strain values in the FBG sensor areas (pushing load case)
	2 000 ÷ 4 000	6 200 ÷ 13 000	range of maximum strain values in the head tube area (pushing load case)

Conclusions

FBG sensors were used for evaluation of critical stresses inside the structural joints of bicycle frame tubes during the ISO defined load cases. Strain value ranges evaluated for this mandatory load cases using the sensors embedded inside the joints were compared to limit strain values evaluated during the strength tests. It was confirmed that critical, from the point of view of rider safety, strain values are well above the values resulting from the required ISO defined standard tests. Moreover, results were used for improving the numerical model of frame and for the further improvement of joint design. Operational tests using the FBG sensors are planned and currently postponed because of the need of miniature optoelectronic measurement device, which is not commonly available.

Acknowledgments

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References

[1] T. Ponížil, Analýza deformací a pevnosti kompozitového rámu silničního bicyklu, Praha, 2019, diplomová práce, FS ČVUT v Praze

[2] International Organization for Standardization. ISO 4210-6:2015(E) Cycles — Safety requirements for bicycles —Part 6: Frame and fork test methods.