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INVESTIGATIONS OF THE SERVICE LOADING HISTORY OF HIGH-PERFORMANCE BICYCLE FRAMES

Key words

Bicycle frames, service loading history, fatigue, strain measurement.

Summary

In the paper, the measurement method and measurements results of the service loading history of mountain bicycle frames are presented. The tests were carried out on the specially selected route corresponding to the working conditions typical for mountain bicycles. A computerised measuring system was applied for the registering of strain values taken from strain gauges. The measurements results were used for elaborating the block loading spectra that will be applied in modelling, calculation and experimental testing of fatigue life of high-performance bicycle frames.

Introduction

One of the key elements of the design process of the objects under cyclically changing loading is the knowledge of service loading histories [1]. It is especially important in the case of the vehicles in which many components are under the threat of the fatigue damage formation because of the diversified influence of many factors of a deterministic and random nature [2, 3].

Examples of the vehicles exposed to the potential occurrence of fatigue processes are bicycles, especially high-performance bicycles, for example, bicycles designed for mountain cycling. The basic component of the high-performance bicycle that determines its sport value is its frame that is one of the most loaded and strained components of the bicycle. Because of the rapid development of new materials and technologies applied in bicycle construction, simultaneous development of frame designing methods are extremely important, including fatigue design methods, allowing one to make the full use of new opportunities which arise from the new technological solutions.

One of the new technologies for preparing semi-fabricated components of bicycle frames is plastic forming of the pipes with the use of compressed oil. This method has produced possibilities of preparing the alternate shape to the profile, which is extremely important in the case of forming the strength and stiffness characteristics of the frames. A wider range of modelling possibilities of the geometric features of bicycle frames are offered by the methods of frame production using composite materials based mainly on carbon fibre. Modern design methods, which use the numerical methods in the fatigue life analysis, provide many possibilities for new frame constructions, allowing one to use them in a way that ensures the most effective exploitation of their properties [4]. However, the application of the modern design methods, in order to prevent the fatigue failure, demands precise knowledge of the course of the service loading history in the considered type of structure. The importance of the quality of modelling of the load in the fatigue analysis is confirmed by numerous papers, including those concerning the frame durability and bicycle reliability. This is why the application of the optimisation methods of the frame design can not be effective without determining the detailed loading conditions, above all, the service loading histories.

The bicycle frames used in the mountain high-performance cycling are operated in very unfavourable conditions. They are subjected to the loadings of high variability forces and strains of considerable amplitude. An additional difficulty is the use of the snap-fastener pedal system, for example, the SPD system (Shimano Pedalling Dynamics). The use of SPD enables the cyclist much more effective pedalling. It nearly eliminates the effect of “dead point,” because it enables the cyclist to both pull and push the pedal.

The result is that the values reached of the forces acting upon the pedals considerably exceed the values observed during typical operating conditions of bicycles. In practice, SPD or other such systems are very often used by experienced cyclists and not only by sportsmen. Loading the bicycle with the use of SPD during intensive use results in much higher forces and a different distribution than expected in normal use.

Publications concerning service loading analysis deal mainly with the typical use of bicycles or are not detailed enough to apply the results in more complex fatigue life analyses.

Obtaining data on loading histories in the most vital nodes of the bicycle frame is essential both because of the work carried out connected with developing a design method for high-performance bicycle frames and from the point of view of the possibility of carrying out simulation tests with the use of the multi-body simulation (MBS), Finite Elements Analysis, and experimental stand verification tests [5].

The problems discussed in this paper are part of the wider research program concerning the analysis of mechanical properties of high-performance bicycle frames with the use of theoretical and experimental methods.

1. The research method and subject of the tests

When analysing the courses of loading in the nodes of the bicycle frame intended for high-performance sports, it is especially important to accurately recreate the nature of the typical racing route and to engage professional cyclists with typical cycling styles and proper fitness preparation. In the case of the off--road and road races in the mountains, the selection of the route seems to be extremely important from the point of view of the accuracy of the following analyses

connected with fatigue life.

Tests of the loading courses in the primary nodes of the bicycle frame were carried out in the natural terrain on a previously selected and described route with the characteristics typical for high-performance mountain bicycle routes using a bicycle with a frame made of welded aluminium with typical geometry for cross-country bicycles (XC) and SPD pedal systems (Fig. 1). The selected route was ridden by cyclists applying one of the typical techniques based on low cadence and heavy pedalling force, which generates strong loading mainly in the support node.

Fig. 1. General view of the bicycle used in the tests

For measurement purposes, 18 strain gauges were attached to the bicycle frame in the chosen places. A detailed description of all measurement points is shown in Figure 2. Figure 3 is a photograph of the bicycle with sensors prepared for the test ride.

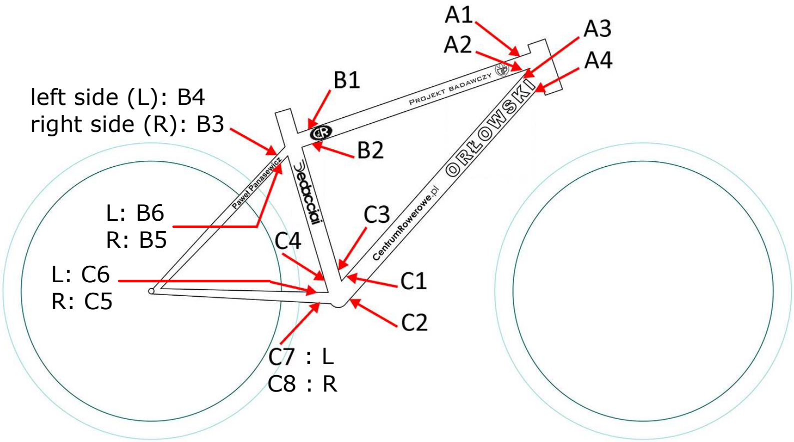


Fig. 2. Measurement points in the high-performance bicycle frame

Fig. 3. Bicycle with the measurement sensors prepared for the test ride

The strain measurements were carried out with the use of ESAM TRAVELLER amplifier connected via USB-2 port with a portable computer equipped with measurement controlling software (Fig. 4). A portable battery power supply for the amplifier and computer enabled the registration of the strain courses in the frame during the ride conditions. During the test, a parallel mode of data registering for eight measuring channels with a registering frequency of 8 kHz was applied, The WESAMUSB software enabled uninterrupted data registration in the computer and the only limitation of the registering time was the hard disc volume and battery durability.

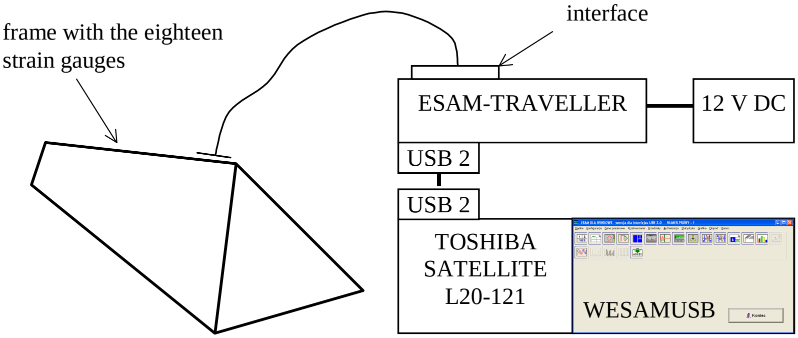


Fig. 4. The scheme of the computer data measurement and registering system

2. Test results

The result of the work carried out was the determination of 48 courses of strain changes in the selected frame areas. Figure 5 presents an example of courses of the strain changes in the four measurement points of the frame registered for a route lasting approximately 400 seconds. The registered courses differ from each other both in the range and in the mean strain value (calculated for the whole course) which depend on the location of strain measurement on the frame.

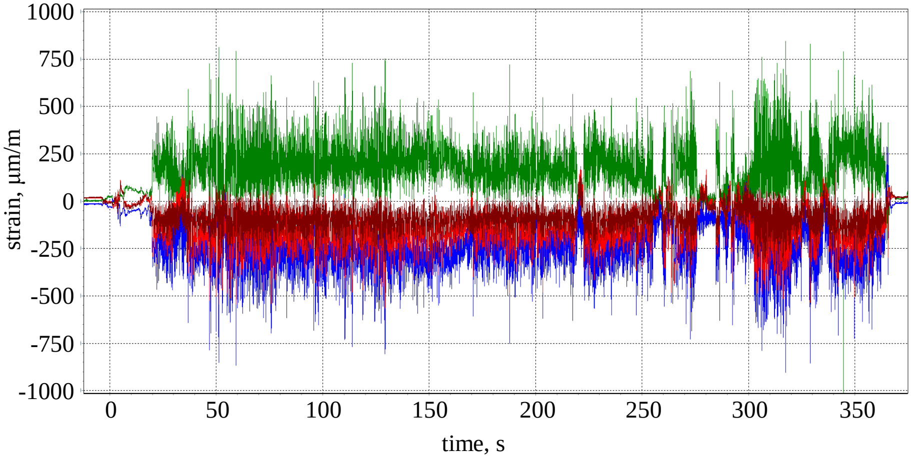


Fig. 5. An example courses of strain changes in four measurement points on the frame

Based on registered service loading histories, normalised block loading spectra for particular frame nodes were determined. Loading spectra were developed using the RAINFLOW counting method according to ASTM standard: ASTM E1049-85(2011)e1 ‘Standard Practices for Cycle Counting in Fatigue Analysis’.

Examples of loading spectra in amplitude-mean value coordinate system determined for two measurement points B1 and B2 in the saddle node of tested frame are shown in Figure 6.

The analysis of presented spectra indicates the typical character of loading for bicycle frame nodes, i.e. with a mean value shift in negative and positive directions for opposite measurement points (see Fig. 2: A1-A2, B1-B2, etc.).

For a comparison of loading intensities, block loading amplitude spectra were determined without mean value analysis. Examples for nodes B and C are shown in Figures 7 and 8. Analysis of an example distribution of relative strain amplitudes ($\varepsilon/\varepsilon_{max}$) shows the significantly higher loading intensity of node B in comparison to node C, particularly in measurement points marked as B1 and B2.

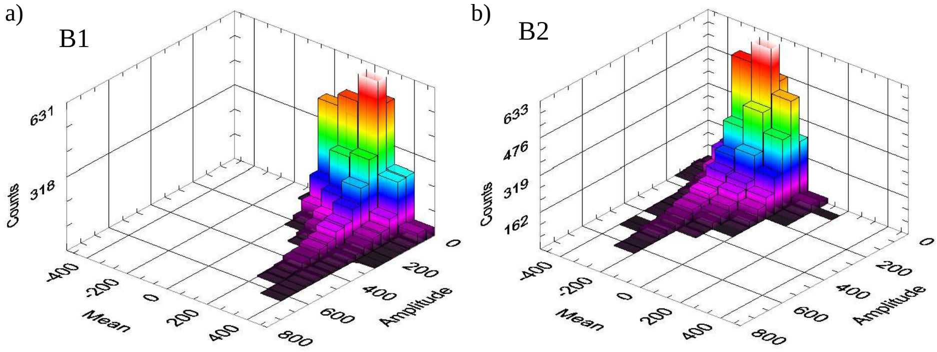
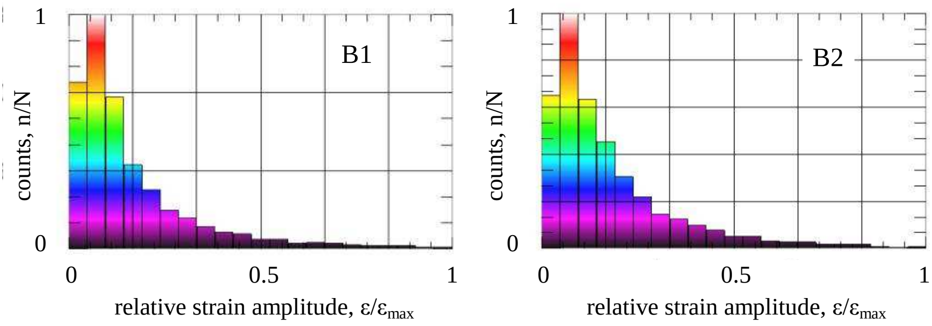


Fig. 6. Loading spectra for two measurements points of node B: with mean values greater then zero (a) and for mean values less then zero (b)



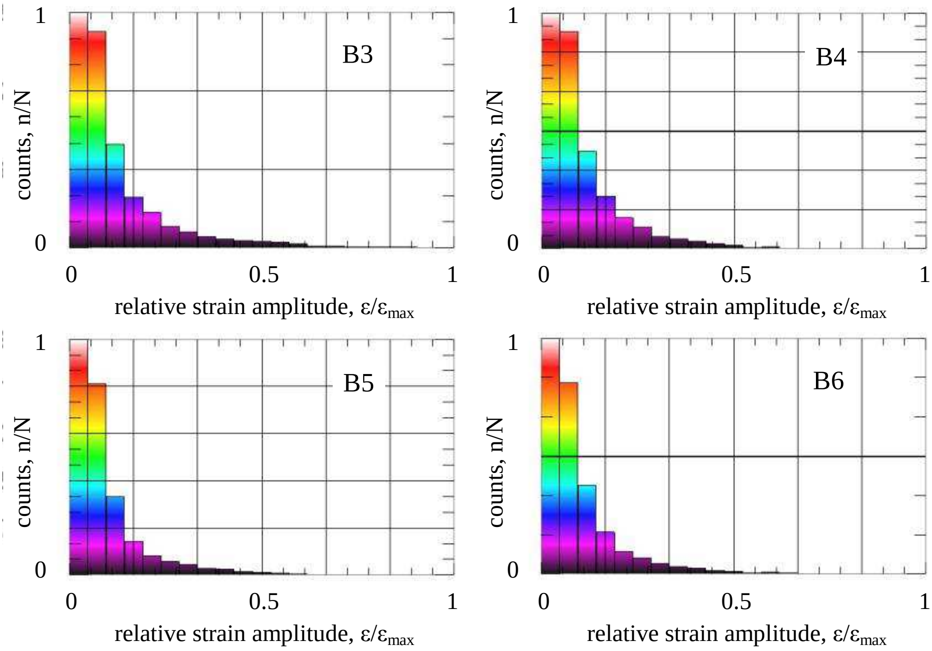
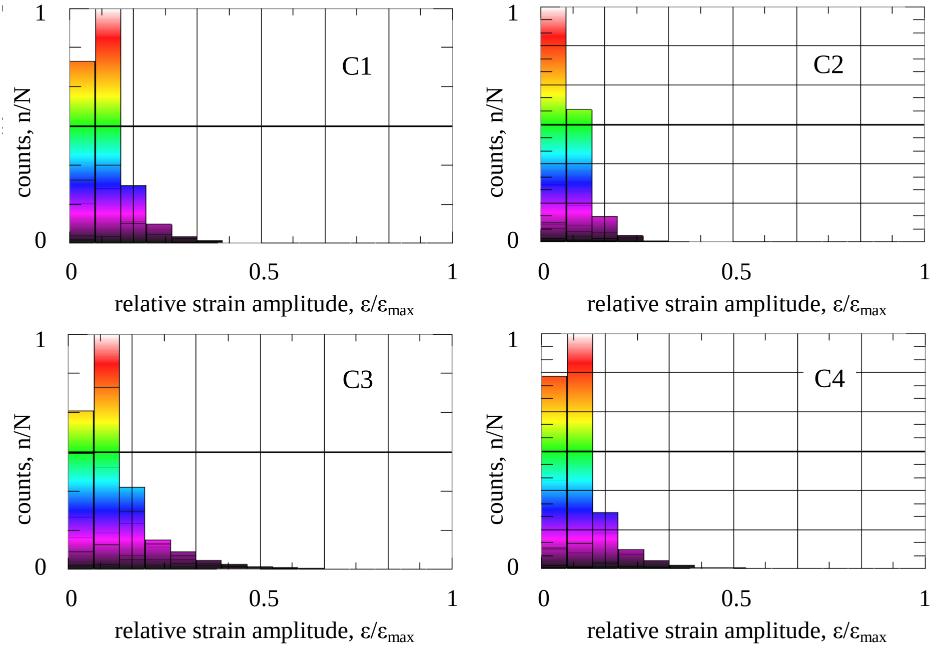


Fig. 7. Loading amplitude block spectra for node B



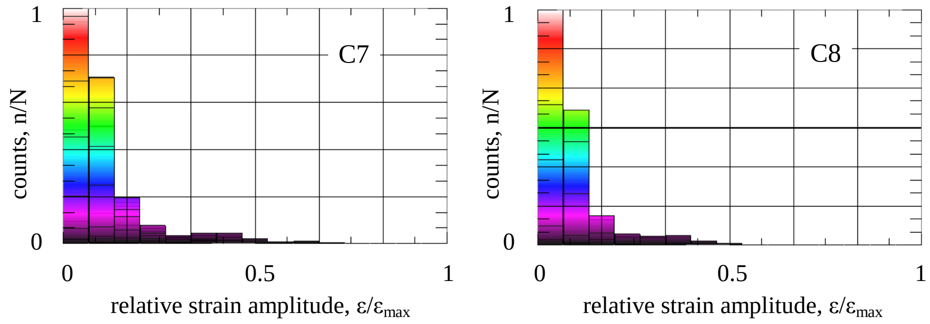


Fig. 8. Loading amplitude block spectra for node C

Conclusions

The research method presented in this paper enabled the registration of the service loading history regarding fatigue analysis frame nodes of a high-performance mountain bicycle frame in the conditions similar to the real service conditions. The registered courses were the basis for the loading spectra development for individual frame nodes, which will be used in the further simulating tests and during verifying experimental tests.

The comparison of the determined loading (strain) spectra in particular frame nodes shows the essential diversity of their character. This is relevant from the point of view of applied design solutions for particular nodes of the bicycle frames with the use of the same material and welding technology, especially taking into account the main purpose of design procedure, i.e. ensuring the same fatigue life for all nodes of a high-performance bicycle frame.

The results of investigations will be supplemented with the results of measurements carried out for different ride techniques that are based on more flexible gear selection and high cadence use with very intensive arms labour. In this case, the head of the frame will be under much heavier loading. This will make it possible to verify the design method of the bicycle frames from the viewpoint of the individualisation of the strength and characteristics to the user's needs.

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Reviewer:
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Badania przebiegów eksploatacyjnych w wyczynowych ramach rowerów górskich

Słowa kluczowe

Ramy rowerowe, historia obciążeń, zmęczenie, pomiary obciążeń.

Streszczenie

W pracy przedstawiono metodę i wyniki pomiarów przebiegów obciążeń eksploatacyjnych w ramie roweru górskiego. Badania przeprowadzono na specjalnie wytypowanej trasie przejazdu odpowiadającej warunkom eksploatacji tego typu rowerów. Do rejestracji wartości odkształceń z tensometrycznych czujników pomiarowych zastosowano skomputeryzowany system pomiarowy. Wyniki pomiarów wykorzystano do opracowania blokowych widm obciążeń, które znajdują zastosowane w obliczeniowej i doświadczalnej analizie trwałości zmęczeniowej wyczynowych ram rowerowych.