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Structural Design and Impact Test of a Suspension Mountain Bicycle Frame by Using FEM Analysis

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Abstract The paper deals with numerical strength analysis of a prototype of full suspension mountain bicycle frame. Frame and its suspension were specially designed to meet predetermined requirements establishing the final properties of bicycle. In the design, also other aspects such as the driving style, characteristic of lines and the figure of driver were taken into account. In this regard, the final design is completely unique. In the paper there are described two impact tests: drop mass and frame drop, which are defined in standard EN ISO 14 766. Both tests were carried out using Finite Element Method.

Keywords: *impact test, mountain bicycle, frame, FEM*

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1. Introduction

Bicycles are very popular means of transport, especially for the younger generation of people who use them for sports, recreation or entertainment. The first bike as we know it today was constructed by British inventor Kirkpotrick Mackmillan in 1839. Since then, bikes have undergone many improvements and gradually spread throughout the world. Although the most widely used means of transport as cars, bicycles are enjoying ever greater popularity. At present the development of mountain bikes is at a very high level and the offer of bicycles for a given discipline of mountain biking is very rich. Manufacturers offer bicycles of various materials, suspension types, damper placing and with the geometry that meets to rider figure and his additional specifications. The most dominant and most expanding discipline of mountain biking is downhill and enduro that have gained a large group of cyclists and also the bicycle manufacturers. Suspension type back construction and geometry of the frame of the bicycle may not always meet the needs of the rider. Therefore it has been designed a bicycle frame which satisfies both downhill and enduro category [1]. The design of this frame required to make some compromises. Several problems were associated with it. They were gradually solved using numerical methods of mechanics [2]. The main emphasis in the optimization of the suspension was placed on a minimum value of pedal bob, low leverage ratio, minimal kickback, progressive working of a damper.

2. Structural Design of the Frame

Figure 1 shows the final design of mountain bicycle. Its frame consists of two basic parts: front and rear triangle. Triangles are mostly formed from pipe profiles and the base material of the frame is steel. A linkage driven single pivot suspension with a high placed main pivotis used to suspension of the rear triangle.

Figure 1. 3D CAD model of mountain bicycle.

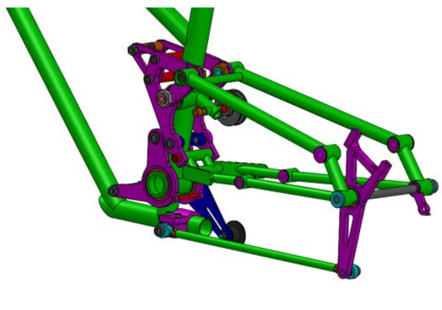

Figure 2. Suspension of rear triangle

In this case, a damper is attached between two lever systems (Figure 2) which are made of an aluminium alloy. This type of suspension is characterized by high sense of spring. The placement of the main pivot more closely to rear wheel axis leads to reducing of pedal kick-back, but also to increase of swinging. Brakesquat effect remains unchanged. Sensitivity to inequality is reduced due to the complexity of the design, but variability of a placing of the pivot pins allows propose the suspension with completely different characteristics. The basic advantages of proposed suspension are:

- the possibility of moving the rear wheel substantially in the horizontal direction,
- progressive spring characteristic,
- high efficiency of pedaling.

Negative influence of pedal kick-back and brake squat was solved by using a tension roller and a floating brake.

3. Short Overview of Impact Tests According to Standard EN ISO 14 766

Standard EN ISO 14 766 deals with safety requirements for bicycles and describes common test methods used to experimental assessment of structural and strength integrity of bicycle frames. In order to fulfill the requirements of the standard, a bicycle frame needs to undergo two impact and two fatigue tests without visible cracks and must respect the envelope ruling the permanent deformation stated for each test. The tests should be performed on a frame/fork assembly. According to the standard, bicycle manufacturers need to perform at least the impact tests using the fork that will be actually sold with the bicycle frame.Ideally, each of the four tests should use a new bicycle frame. This paper deals only with impact tests. Standard EN ISO 14 766defines two types of impact test: mass drop and frame drop [3].

3.1. Impact Test 1: Drop Mass

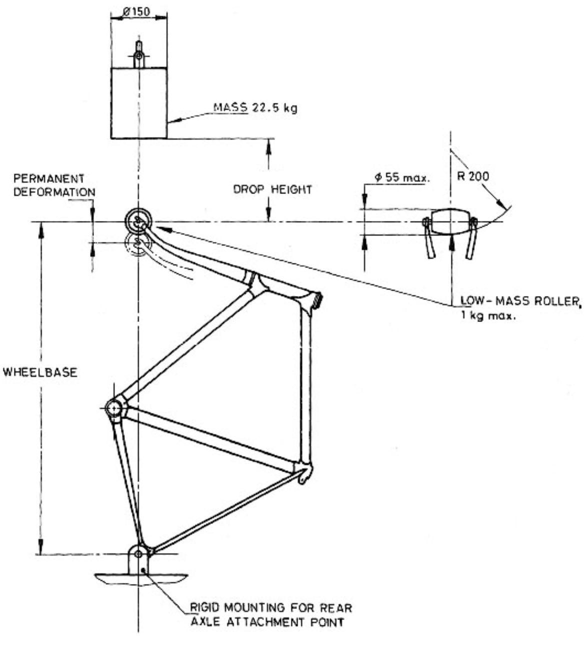

Figure 3. Setup of impact test: Drop mass [3]

A mass of 22.5 kg falls from a height of 360 mm and drops on precisely defined contact component which is firmly connected to the axis of a fork. During the test, the assembly frame/fork is in the vertical position and can rotate about the axis of rear wheel. After the test no visible cracks are desired. Maximal permanent deformation between the two axes must be below 30 mm. Setup of the test is shown in Figure 3.

3.2. Impact Test 2: Frame Drop

Two masses of 25 kg are placed on both sides of bottom brackets. The next mass of 30 kg is placed on the seat post having its center of gravity 75 mm away from the extremity of the frame seat tube end. A mass of 10 kg is placed on upper side of head tube instead of stem. A contact component the same as in the previous test is connected to the front fork. The frame has the possibility of rotation about the rear wheel axis and is rotated to such a position that the vertical distance between the front axis and the steel anvil is 300 mm. Subsequently, the whole assembly is released from this position and falls freely. Setup of the test is shown in Figure 4. Tested frame satisfies the test if a maximum permanent change of a wheelbase (without cracks) is less than 60 mm.

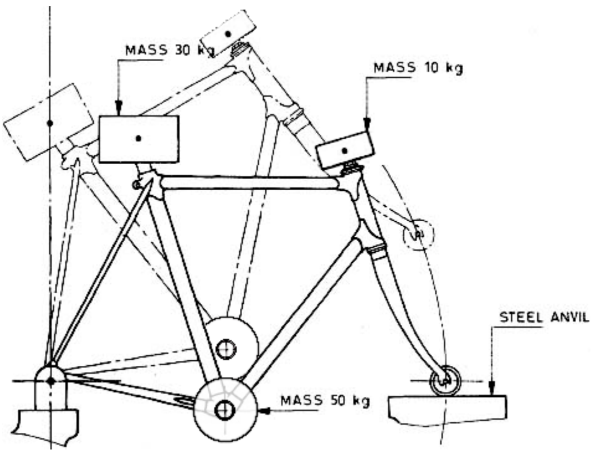

Figure 4. Setup of impact test: Frame drop [3]

4. FEM Simulations

Impact tests described in the previous section were carried out in SolidWorks Simulations software. Quadratic tetrahedral elements were used to mesh the geometric model of bicycle frame. Surface contacts (without friction) between components were considered in simulations.In both cases the nonlinear dynamic analysis was performed therefore elasto-plastic Von Mises material model had to be used. Material properties of its individual parts are shown in Table 1. In Figure 1 and Figure 2, steel parts are green and aluminium parts are purple.

Table 1. Properties of used materials

	Steel 25CrMoS4	Aluminium alloy Al Zn6CuMgZr
Young's modul	205 000 MPa	72 000 MPa
Poisson's ratio	0,285	0,33
Yield strength	460 MPa	435 MPa
Tensile strength	730 MPa	495 MPa
Density	7850 kg/m^3	2830 kg/m^3

Springs and dampers were replaced by rigid elements due to simplification of solutions and time saving. Consequently, calculated stresses and strains are greater than in reality when springs and dampers absorb a part of impact and deformation energy.

4.1. Impact Test 1: Drop Mass

The model of analyzed frame was oriented parallel to gravity and its rear wheel axis was pivotally mounted to base. Mass of 22.5 kg was placed to a contact plane tangent to the contact component that was mounted at the front wheel axis. The initial velocity of mass (velocity on impact) was calculated as

$$v = \sqrt{2gh} = \sqrt{2 \cdot 9.81 \cdot 0.36} = 2.658 \ \text{m}\,\text{s}^{-1}, \qquad (1)$$

where g is gravity acceleration and h is drop height.

Boundary conditions of FE model are shown in Figure 5.

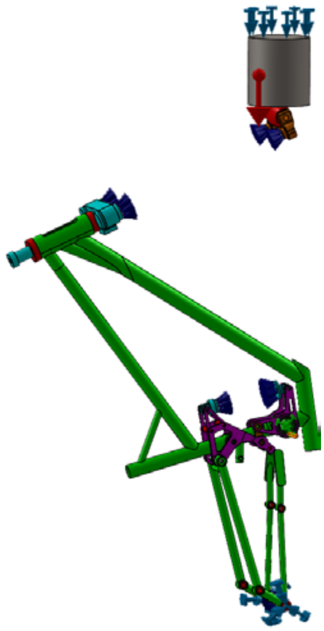

Figure 5. Geometrical model and boundary conditions for impact test 1

Figure 6 shows the field of maximum reduced stresses on a part of the frame. As can beseen, the maximum stress (436.4 MPa) is on the edge between the down and head tube. The time dependence of a reduced stress in that place is shown in Figure 7.

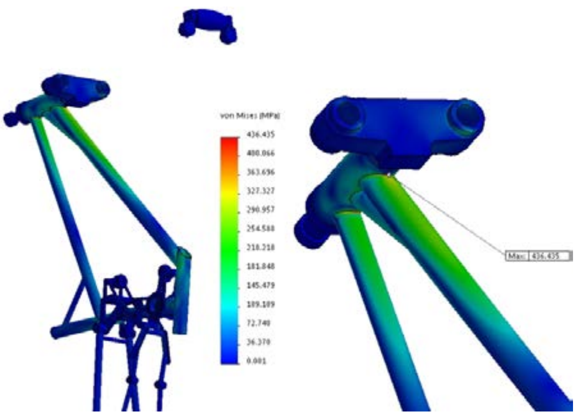

Figure 6. The field of maximum reduced stress at the time 0.012 s

Maximum displacement was recorded in vertical direction at the time 0.012s after the impact. Displacement field at this time point is shown in Figure 8. Maximum value (11.47 mm) corresponds to maximum change of a wheelbase.

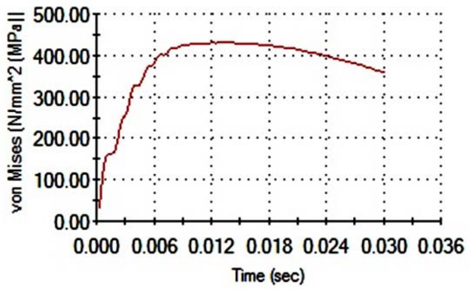

Figure 7. The time dependence of maximum reduced stress

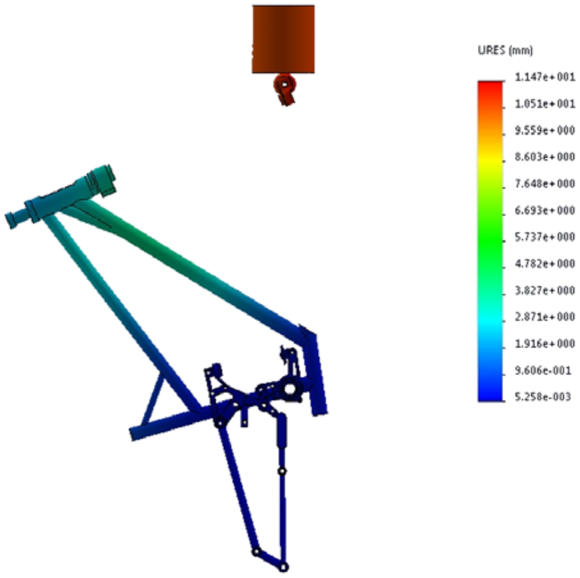

Figure 8. Displacement field at the time 0.012 s

Since the maximum stress did not exceed the yield strength and the deformation was only elastic, the frame satisfied the test.

4.2. Impact Test 2: Frame Drop

In this case, the model of the frame was oriented normal to gravity and pivotally mounted at its rear wheel axis. Masses (50, 30 and 10 kg) were applied exactly according to Figure 4. The contact component was put on rigid block representing an impact anvil. The initial velocity of a component furthermost to the rear axis was set to 2.426 m s^{-1}. Boundary conditions of FE model are shown in Figure 9.

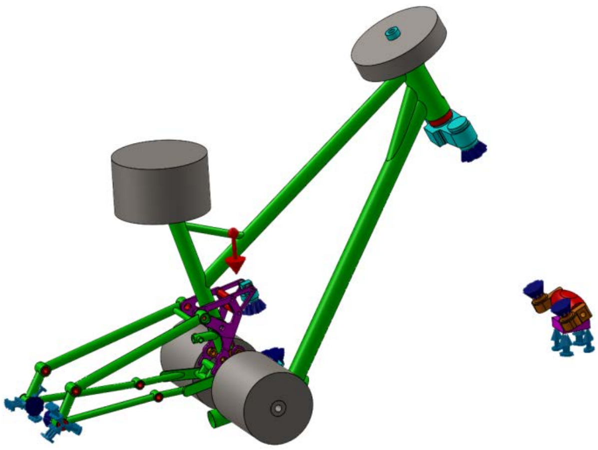

Figure 9. Geometrical model and boundary conditions for impact test 2

Maximum reduced stress was recorded at the area of the rear triangle and a seat tube at the time 0.09 s. Maximum stress at this time was 309 MPa (see Figure 10). This value was identified in one node in a place where bearing contact was defined. The time dependence of maximum reduced stress is shown in Figure 11. Since its value did not exceed the yield strength and the deformation was only elastic, the frame satisfied this test too.

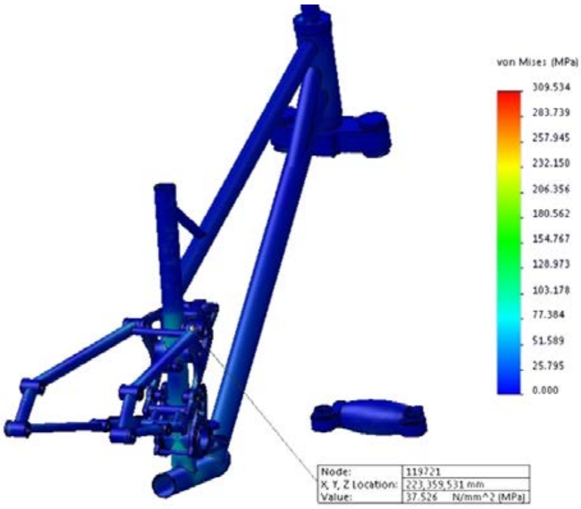

Figure 10. The field of maximum reduced stress at the time 0.09 s

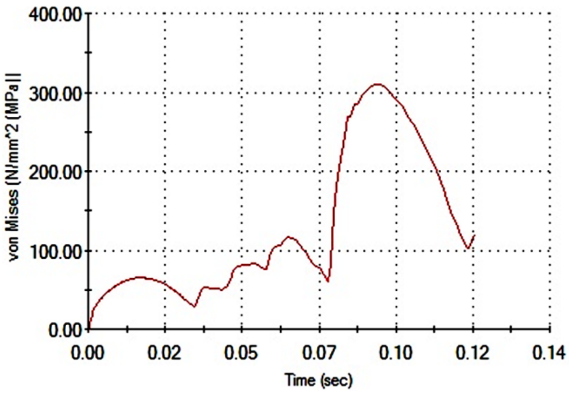

Figure 11. The time dependence of maximum reduced stress

Maximum displacement at the time 0.09 s was 4.42 mm. Corresponding displacement field is shown in Figure 12.

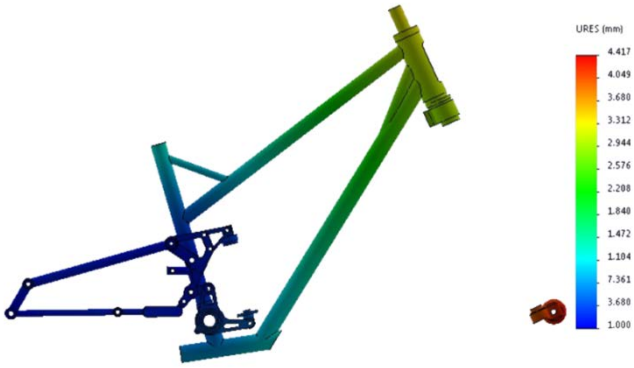

Figure 12. Displacement field at the time 0.012 s

5. Conclusion

In this paper the structural design and the impact tests of full suspension frame of the mountain bicycle was presented. An aim of the design was to join characteristics of enduro and downhill bicycle. This was achieved by special design of rear triangle suspension. In this regard, the final bicycle has unique driving characteristics. Structural integrity of the proposal frame was verified by two impact tests defined in standard EN ISO 14 766. Both tests were performed by using Finite Element Method. The results of simulations show that the frame is strong enough.

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