The 9th International Symposium
KOD 2016
Konstruisanje • Oblikovanje • Dizajn
9-12 June 2016
Balatonfüred, Hungary
Novi Sad - Timisoara - Szeged

A NEW CONCEPT OF BICYCLE FRAME DESIGN

Marija MATEJIC
Milos MATEJIC
Marijana MILICEVIC
Lozica IVANOVIC

Abstract: *For the research purposes two of bicycle frame concepts have been developed. The biggest attention is given to the aesthetic and ergonomic aspects. After developing the concept of bicycle frames, their CAD models are created and FE analysis is performed. The distribution of loads is examined in critical frame areas, as well as deformation occurred under the influence of the real working load. The discussion of the results is performed and recommendations are given how the proposed conceptual solutions can became practically feasible. At the end of the paper are given the directions for further research on this topic.*

Key words: *bicycle, bicycle frame, design, FE analyses*

1. INTRODUCTION

Developing of new products, for widespread usage, is tight related to the industrial design principles [1]. Following of this principles greatly increases the possibilities of the product success on the market. After the first working concept of bicycle, which is designed by Kirkpatrick Macmillan, 1839, there is no a second and third. Ordinal numbers give way to the improved details, new frame designs and improved ergonomics, but original concept stays the same.

The innovative ideas of the manufacturers and construction designers to minimize aerodynamic drag, to improve comfort, minimizing the mass of the frame, maximizing lateral stiffness in the load transfer from the hands and feet to the drive, maximizing the strength capabilities of the frame to allow for a higher load capacity or better load distribution, and adjusting the vertical compliance of the frame to tune the softness of the ride [2, 3] that means comfort and safety ride. These are the reason of contribution in the development occurs in the design of bicycle frame and consequently the need of analysis of bicycle structure come to rise. The frame of the bicycle is the main structure to support the external loads. Traditional materials of the bicycle frame are the steel or aluminum alloy. With help of theoretical or numerical calculations, the strength and stiffness of the bicycle structures can be predicted and modified to the optimal design before the manufacture of the prototype and actual commercial products.

A promising solution is provided by a tool of structural engineering; the Finite Element analysis. Performing Finite Element Analysis (FE analysis) on bicycle frames has become a common activity for bicycle designers and engineers in the hope of improving the performance of frames. This is typically achieved by balancing priorities for key requirements, including minimizing the mass of the frame (possibly using competition rules to constrain this), maximizing lateral stiffness in the load transfer from the hands and feet to the drive, maximizing the strength capabilities of the frame to allow for a higher load capacity or better load distribution, and adjusting the vertical compliance of the frame to tune the softness of the ride. Depending on the type of physical problem being analyzed, the field variables may include physical displacement, temperature, heat flux, and fluid velocity to name only a few [4]. A lot of work is done on the analysis of bicycle frame; some of that work is presented here. FE analysis has been used to analyze composite, aluminum and steel bicycle frames [5–8] with the aim of understanding physical behavior and improving performance relating, however a comprehensive study on the influence of key geometric parameters on the stiffness of frames has not been conducted. Soden and Millar [9] used “beam” elements to evaluate stresses of a steel bicycle frame during common cycling situations and compared the FE results with the experimental ones based on strain-gauges measurements. Hull and Bourlochi [10] proposed a new design method based on a FE analysis evaluation of bicycle frame stresses at several crank angles. Davis and Hull [11] are analyzed the design of aluminum frame bike to fatigue failure. Numerous studies in this field have been carried out in terms of the load and the ergonomic aspects of the analysis on the existing bike frames. There are a smaller number of researches done on the topic of improving the design of the bicycle frame.

Those activities proposed FE analysis as an instrument to improve frame performances in term of strength, high stiffness and low weight by means of a better knowledge of stresses. The designer, using FE analysis, knows which part of the frame is more stressed and could modify the thickness of the tube or its mean diameter.

The authors of the paper used the methodology of industrial design with a concept that includes the analysis of objective circumstances to design two bicycle frames. From the aspect of industrial design, special attention was paid to the aesthetic appearance and ergonomic properties of the bicycle frame. In order to comprehend the real conditions in which the product will be used, creating a 3D models and technical documentation is conducted in the software package Autodesk Inventor Professional 2014®. The aim is to create the shape of the product in accordance with the requirements of technology features, ergonomics and markets, using computer programs which results provide visual and other information necessary for making real product scheduled for industrial production.

To meet the requirement for the design of a bicycle frame is necessary to consider the influence of other components of the bicycle in different exploitation conditions.

2. CONCEPTUAL DESIGN CHOISES

Based on preliminary review of available literature sources and existing solutions bicycle frame design, it is accessed the innovative development of two bicycle frame concepts (Fig. 1).

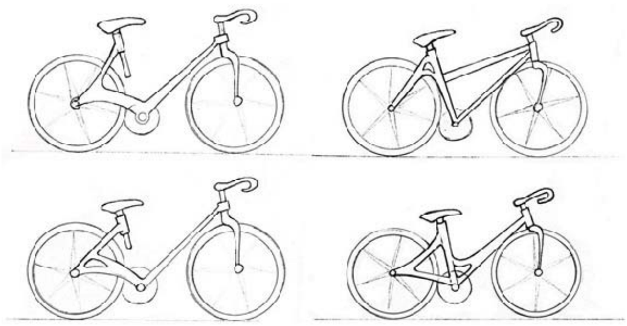

Fig.1. Conceptual design of the bicycle frame

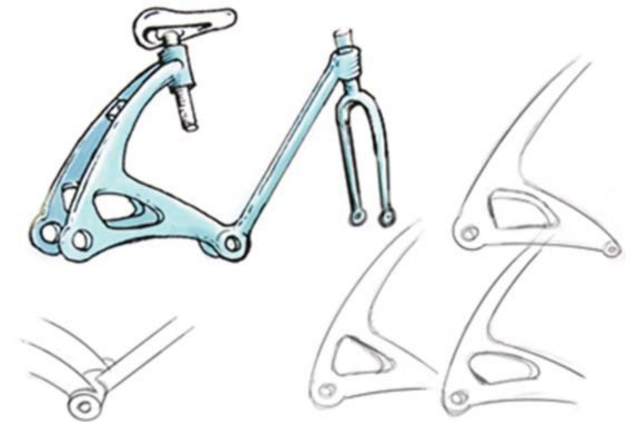

Fig.2. Concretization of the new bicycle frame solution

The final setup of the bicycle frame includes a set of pipes and plates. Frame can be observed as two parts, front and rear. The rear part of the frame is composed of circular pipes ∅28 mm, with a wall thickness of 2 mm and two curved plates with thickness of 7 mm. The plates are curved in a form of the letter "A". The front part consists of a circular pipe ∅34 mm, curved pipes elliptical shape and rectangular full profile page 7 mm and 20 mm. The front and rear sections are connected through a circular pipe ∅38 mm, with a wall thickness of 9 mm. The frame is made of aluminum. Piping parts and panels are welded. Overall dimensions of the frame are 926 mm and 572 mm.

3. FE ANALYSIS OF BICYCLE FRAME

Basic requirements to the bicycle frame must fulfill is holding other components of bicycle at certain distances. The frame is a stationary part of the bicycle. Deformation of this part may lead to damage of the whole bicycle, so it is recommended detailed stress analysis.

3.1. Analysis of first bicycle frame concept

Finite element method has been used for testing a new model of bicycle frame (Fig. 3.), and preliminary analysis results are obtained. Analysis of stress and strain state is conducted in Autodesk Inventor 2014®. Discretization of bicycle frame is performed by three-dimensional finite element mesh, which is in the form of parabolic tetrahedron.

Fig.3. First bicycle frame CAD model

Constraints are placed in two places: at the rear axle and on the point where the steering pipe relies on a fork. The constraints are shown in Fig. 3. Bicycle frame is loaded with the forces in the value of 2000 N, places the seat and steering wheel (Fig. 4.)

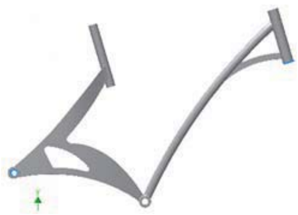

Fig.4. First frame constraints

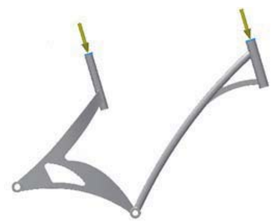

Fig.5. First frame loads

3.2. Analysis of second bicycle frame concept

In the bicycling world, the weight of the bike is very important characteristic. The only part of the bicycle which could support changes of weight is bicycle frame. The new frame design that has been tested in the previous section did not show satisfactory results, and gain access to redesign solutions. Changes were made at the last, and the front of the shoulder. Plates that are planned as bearing parts of the rear of the facilitation. They are also the reduced thickness. The thickness of the board now is 6 mm. In front of the frame, the reducing volume of pipe 4 mm reduces weight. In Figure 6, you can see the model created in the aforementioned gives software package.

Fig.6. Second bicycle frame CAD model

4. ANALYSIS RESULTS

Displacements, which occur due to the operation of the present loading of the frame design, are shown in Figure 7. The maximum deflection of the pipes in place a seat pipe and it is 2.314 mm. At the rear axle, there is no deformation.

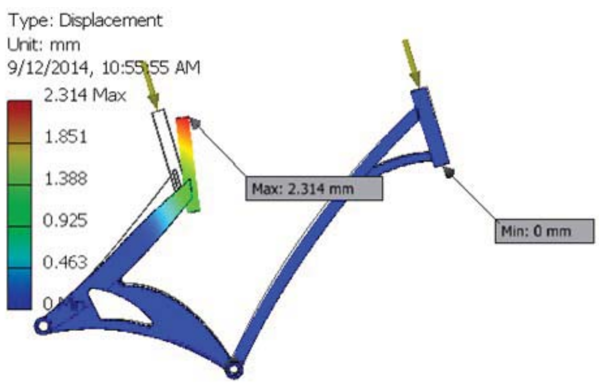

Fig.7. Displacement of first frame

Von Misses stresses are shown in Figure 8. The maximum stress is on the place where is the bicycle fork is 213.2 MPa.

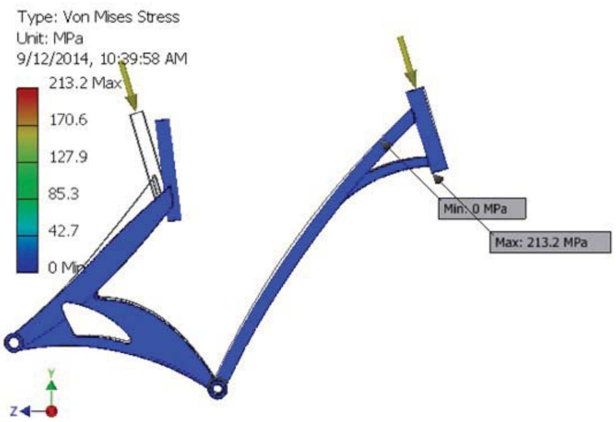

Fig.8. Von Misses stress of the first frame

Deformations on the loaded design of the frame are shown in Figure 9 and show the maximum deformation in place a seat pipe, and it is 3.318 mm. There is no deformation at the rear axle.

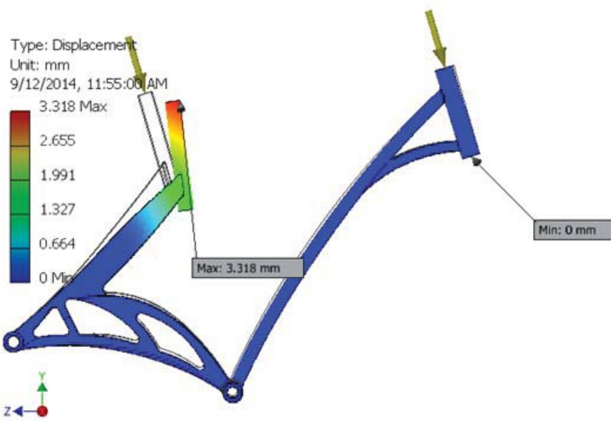

Fig.9. Displacement of the second frame

Von Misses stresses are shown in Figure 10. The maximum stress on the inside, at the place cuttings plate and it is 125.2 MPa

Fig.10. Von Misses stress of the second frame

Because of the stress concentration at radiuses, the mesh elements are smaller at those spots. Results that are more accurate can be obtained if mesh elements is changed to the brick elements. This operation wasn't an option because it hard to perform brick elements on the complex shapes like these bicycle frames.

5. DISCUSSION OF THE RESULTS

The obtained numerical results displacement and Von Misses stress led to the conclusion that a new conceptual solution of first bicycle frame will support the load that has been assigned. The new frame was required, and weight reduction, as this design has not been achieved. The second frame is heavier compared to existing frames by 0.29 kg. In order to reduce weight is recommended to facilitate their cup or plate thickness.

The weight of the first frame is larger than second bicycle frame. Second bicycle frame weighs 1.962 kg. By reducing, the weight decreased and the stress obtained at the initial results of the second solution. Critical stress is now located at the rear of the frame. The disadvantage of this solution is the deformation. Both solutions greatest deformation at the target seat pipe and second bicycle frame displacement 3.318 mm. The value of this displacement is small, less than 4 mm, or viewed in relation to a given initial solution that is eight times larger. To check whether this displacement is negligible recommended conducting additional analysis that would give relevant information. Table 1 presents a comparative overview of the results of first and second bicycle frame with a given displacement and Von Misses stresses.

Table 1. Comparison gained results of the first and second bicycle frame

	First frame	Second frame
Max displacement	**2.314 mm**	**3.318 mm**
Max stress	**213.2 MPa**	**125.2 MPa**
Mass	**2.51 kg**	**1.962 kg**

6. CONCLUSION

Based on the literature sources presented in this paper, we can say that the research topic is extremely relevant and attractive, since the creation of the bike to the present day. Many researchers have been working on the analysis of how the bike, an extremely widespread means of transport do even better.

For the purposes of this study were developed two concept bike frame. Both concepts are developed original solutions. In both concepts, the primary goal was to meet the aesthetic and ergonomic requirements. For both conceptual solutions are developed CAD model, to which reference is made FE analysis. In both models is adopted as the material aluminum. After the analysis of the resulting stresses and displacements. The stresses and displacements for selected material in larger limits than allowed. To make this conceptual solutions bicycle frame made, in practice it is necessary to change the types of materials or to the critical areas amplification device that would prevent displacement and reduce stress concentration.

This is an improvement, which is planned, in the further work using the methods of structural and topological optimization. In future research on this topic in the elaboration of the plan obtained by the methods of structural frames and topological optimization. Such an approach would in the future, combined with FE analysis, and gave excellent results.

REFERENCES

[1] Ivanović, L., Kuzmanović, S., Vereš, M., Rackov M. & Marković B. (2015). *Industrial design*, Faculty of Engineering University of Kragujevac, Kragujevac, ISBN 978-86-6335-017-5

[2] Hastert A., Barger B., Wood T., Finite Element Analysis of a Sandwich Composite Bicycle Frame, www.labmilwaukee.com/wpcontent/uploads/2011/08/bikefea.pdf Pages 6.

[3] Cichański A., Tomaszewski T., (2010). Numerical verification of quasi-static strength of the horizontal bicycle welded frame. *Journal of Polish CIMAC*

[4] Arola D., Rainhall G., Jenkins M., Iverson C., (1999) An Experimental analysis of hybrid Bicycle frame. *Experimental Techniques* 23:21–24.

[5] Peterson L., Londry K. (1986). Finite-Element Structural Analysis: A New Tool for Bicycle Frame Design, T*he Strain Energy Design Method. Bike Tech: Bicycling Magazine's Newsletter for the Technical Enthusiast*, 5:2:158-164.

[6] Lessard L., Nemes J., Lizotte P. (1995). Utilization of FEA in the design of composite bicycle. *Composites* 26:72–74.

[7] Maestrelli L., Falsini A. (2008). Bicycle frame optimization by means of an advanced gradient method algorithm. *2nd European HTC*, Strasbourg.

[8] Liu T., Wu H. (2010). Fiber direction and stacking sequence design for bicycle frame made of carbon/epoxy composite laminate. *Materials and Design*, 31:1971–1980.

[9] Soden D., Millar A., Adeyefa A., Wong S. (1986). Loads, stresses and deflection in bicycle frames. *Journal of strain analysis,* 21:185–195.

[10] Hull L., Bourlouchi F. (1988). Contribution of rider-induced loads to bicycle frame stress. *Journal of strain analysis*, 23:105–114.

[11] Davis R., Hull L. (1981). Design of Aluminum Bicycle Frames. *Journal of Mechanical Design*, 103 (4): 901-907.

CORRESPONDENCE

Marija MATEJIĆ, M.Sc, PhD student,
University of Kragujevac, Faculty of Engineering,
Sestre Janjic 6
34000 Kragujevac, Serbia
marija.jeremic@kg.ac.rs

Miloš Matejić, M.Sc., Teaching Assistant,
Faculty of Engineering,
Sestre Janjic 6
34000 Kragujevac, Serbia
mmatejic@kg.ac.rs

Marijana Milićević, M.Sc.,
Faculty of Engineering,
Sestre Janjic 6
34000 Kragujevac, Serbia
mmilicevic90@gmail.com

Lozica IVANOVIĆ, Assoc. prof. Ph.D.
University of Kragujevac
Faculty of Engineering
34000 Kragujevac, Serbia
lozica@kg.ac.rs