Ministry of Education and Science of Ukraine
Black Sea Universities Network

ODESA NATIONAL UNIVERSITY OF TECHNOLOGY

International Competition of Student Scientific Works

BLACK SEA SCIENCE 2022

PROCEEDINGS

ODESA, ONUT 2022

Ministry of Education and Science of Ukraine

Black Sea Universities Network

Odesa National University of Technology

International Competition of Student Scientific Works

BLACK SEA SCIENCE 2022

Proceedings

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Odesa National University of Technology, 2022.

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INTRODUCTION

International Competition of Student Scientific Works “Black Sea Science” has been held annually since 2018 at the initiative of Odesa National University of Technology (formerly Odesa National Academy of Food Technologies) with the support of the Ministry of Education and Science of Ukraine. It has been supported by Black Sea Universities Network (the Association of 110 higher education institutions from 12 countries of the Black Sea Region) since 2019, and by Iseki-FOOD Association (European Integrating Food Science and Engineering Knowledge into the Food Chain Association) since 2020.

The goal of the competition is to expand international relations and attract students to research activities. It is held in the following fields:

- Food science and technologies
- Economics and administration
- Information technologies, automation and robotics
- Power engineering and energy efficiency
- Ecology and environmental protection

The jury includes both Ukrainian and foreign scientists. In the 4 years that the competition has been held, the jury included scientists from universities of 24 countries: Angola, Azerbaijan, Benin, Bulgaria, China, Czech Republic, France, Georgia, Germany, Greece, Israel, Italy, Kazakhstan, Latvia, Lithuania, Moldova, Pakistan, Poland, Romania, Serbia, Slovakia, Switzerland, Turkey, USA.

At the same time, every year the geography has expanded and the number of foreign jury members has increased: from 46 jury members representing 25 universities from 12 countries in 2018, to 73 jury members of the 46 universities from 19 countries in 2022.

More than a thousand student research papers have been submitted to the competition from both Ukrainian and foreign institutions from 25 countries: China, Poland, Mexico, USA, France, Greece, Germany, Canada, Costa Rica, Brazil, India, Pakistan, Israel, Macedonia, Lithuania, Latvia, Slovakia, Romania, Kyrgyzstan, Kazakhstan, Bulgaria, Moldova, Georgia, Turkey, Serbia.

The interest of foreign students in the competition grew every year. In 2018, the students representing 15 institutions from 7 countries have submitted 33 works. In 2021 the number of submitted works increased to 73, authored by the students of 40 institutions from 18 countries.

The competition is held in two stages. In the first stage, student research papers are reviewed by members of the jury who are experts in the relevant fields. In the second stage of the competition, the winners of the first stage have the opportunity to present their work to a wide audience in person or online.

All participants of the competition and their scientific supervisors are awarded appropriate certificates, and the scientific works of the winners are included in the electronic proceedings of the competition. Every year the competition receives a large number of positive responses from Ukrainian and foreign colleagues with the desire to participate in the coming years.

3. INFORMATION TECHNOLOGIES, AUTOMATION AND ROBOTICS

MODELLING AND INVESTIGATION OF THE INFLUENCE OF BICYCLE FRAME DESIGN PARAMETERS ON ITS ERGONOMIC PROPERTIES

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Abstract. *It is impossible to imagine the modern world without the widespread use of such an environmentally friendly mode of transport as the bicycle. Many developers around the whole world have created a large number of models of this type of transport. Development of bicycling is linked to the emergence of new technologies, materials and design concepts. There are many variations in bicycle frame designs. The study of the influence of bicycle design parameters on its handling and comfort is an urgent scientific and technical task.*
The subject of the study is the design parameters of the bicycle frame.

The soundness and robustness of the scientific positions are ensured by the use of the fundamental principles and methods used in geometry, physics, and the modern SolidWorks Simulation package.

Practical value. The use of the obtained results makes it easier to select a bicycle according to people's parameters. The parametric model of bicycle frame was also developed, which is the basis for further detailed analysis of bicycle operation under different kinds of loads.

Keywords: *frame design parameters, ergonomic properties, loads, displacement, manoeuvrabilit, wheelbase, controllability.*

I. INTRODUCTION

It is impossible to imagine the modern world without the widespread use of such an environmentally friendly mode of transport as the bicycle. Many developers around the whole world have created a large number of models of this type of transport. Development of bicycling is linked to the emergence of new technologies, materials and design concepts. There are many variations in bicycle frame designs. The study of the influence of bicycle design parameters on its handling and comfort is an urgent scientific and technical task.

The subject of the study is the mechanical processes that occur when using a bicycle.

The subject of the study is the design parameters of the bicycle frame.
The aim of the study is to determine the nature of the relationship between the ergonomic properties of the bicycle and the design parameters of the frame.

In order to achieve the goal, the following tasks need to be solved:

1. Analyse the different types of bicycles and identify the design parameters and the limitations on them.
2. Determine the criteria for the quality of the bicycle and analyse the influence of its design parameters on its ergonomic properties by means of analytical studies.
3. Build a parametric three dimensional model of the bike and its frame.

4. Using state-of-the-art methods of tri-modelling and structural analysis packages, analyse the strength of the bicycle frame structure.

Research methods: The research is based on the analysis and classification of bicycles, analytical studies, and the use of modern methods of trivimetric modelling and scintillation analysis packages.

In the course of the work, a parametric trivimetric bicycle model had to be created and a computer experiment had to be carried out using this model. The results of the investigation on the model show the correlation between the design parameters of the frame and the properties of the bicycle.

Scientific positions:

The radius of the bicycle's turning circle is directly proportional to the length of the wheelbase and wrapped proportionally to the cosine of the front wheel's understeer.

The bike's manoeuvrability and stability is affected by the wheelbase, handlebar grip, carriage position and the seat tube and handlebar grip.

The strength of the frame is influenced by the material, the parameters and the orientation of the cross-section of its components. The maximum forces exerted by the cyclist's weight are localised at the junction of the lower and inner tubes, so the strength of the frame is also greatly influenced by the welding quality of the frame components.

The soundness and robustness of the scientific positions are ensured by the use of the fundamental principles and methods used in geometry, physics, and the modern SolidWorks Simulation package.

II. LITERATURE ANALYSIS

ANALYSIS OF THE STATE OF PLAY AND STATEMENT OF RESEARCH OBJECTIVES

2.1. Relevance

The development of new mechanics is based on the testing of different types of materials, component bases, processing and integration technologies and long-term performance tests under different operating conditions. As for the bikes themselves, the new models have to take into account the requirements for ergonomics and price. Therefore, the task of computer model of the bicycle for research on the correlation between the design parameters of the bicycle and its ergonomic properties is very relevant. Detection of such correlations can simplify the task of finding a balance between using new, expensive materials and reducing the cost of the final model without losing the quality and properties attributed to each individual model.

The use of computer-aided simulation allows substantial savings in terms of new, expensive materials and reduced testing time. In the end, the result is a lower cost of production and greater competitiveness on the market.

We therefore consider the topic of our study to be relevant and useful.

2.2. Varieties of bicycles and their classification

The purpose of bicycles can be divided into 6 big groups [1], namely: mountain bikes, road bikes, racing bikes, touring bikes, track bikes and BMX bikes.

Mountain bikes (Fig.1a) are designed for off-road riding. These bikes are distinguished from the others by their very sturdy frames and wheels, wide tyres with high tread and a strong kerb, which are essential if the driver is to be able to withstand road shocks.

Road bikes (Fig.1 b) are designed for cycling and walking. These bikes are equipped with full, front and rear frames and a lancet guard to keep the rider clean. The tyre and frame weights are medium to high. The seat is both straight and very straight.

a)

b)

c)

d)

Fig.1 – Bicycle types [1]
a – dirt bike; b – road bike; c – track bike; d – touring bike; e – racing bike; f – bike for performing tricks

Track bikes (Fig. 1 c) are designed for riding on a cycle track. This type of bike is similar in appearance to road bikes. Due to the short wheelbase, the frame stiffness increases. The bike has only one gear. The track bike can only be ridden in a single gear.

Touring bikes (Fig. 1 d) are designed for long journeys and cycling. They are suitable for riding on unpaved roads as well as on municipal roads. Fitted with lights, fenders and luggage compartment. The handlebar is straight.

2.3. Summary of the section

Bicycles can be divided into six major groups, namely: mountain bikes, road bikes, dirt bikes, dirt bikes, touring bikes, trail bikes and BMX bikes for performing tricks.

The parameters of the bike frame depend on the intended use of the bike.
The parameters of the bike frame affect the bike's ride, handling characteristics, manoeuvrability, directional stability and usability.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

INVESTIGATION OF THE INFLUENCE OF BICYCLE PARAMETERS ON THE BIKE'S RIDE

Let's look at the ergonomic properties of the bicycle. These include the suitability of the frame height, the size of the bicycle wheel to people's height; the seat angle; manoeuvrability and controllability, i.e. the dependence of the bicycle turning radius on the handlebar turning angle; rudder safety; the position of the bicycle centre of gravity with the rider for different track gradients.

3.1. Parametric bicycle frame model

The geometry of the bike frame can be characterised by a set of parameters, including the length of the frame components.

The standard [2] developed by the Research and Development Institute for Standardization and Certification in Mechanical Engineering has the following basic bicycle parameters. These include the limitations that must be observed when designing a new bicycle.

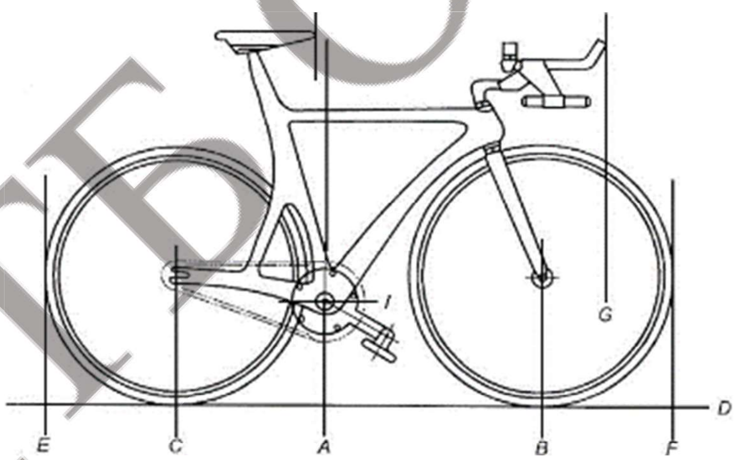


Fig. 2. Basic bicycle parameters and dimensions

Dimensions: length EF ≤ 1.9 m; width no more than 0.55 m and for VMX no more than 0.74 m.

The distance between the horizontal line drawn through the centre of the carriage I and the ground surface D must be at least 0.2 m and no more than 0.3 m.

The distance between the vertical lines drawn through the centre of carriage A and the centre of the front wheel B is 0.43 - 0.75 m.

The distance between the vertical lines drawn through the centre of carriage A and the centre of the rear wheel C is 0.25 - 0.55 m.

The distance between the vertical lines drawn across the front seat point H and the centre of carriage A must be at least 0.05 m behind the carriage, except on sports bikes. For sports bikes, this distance can be zero.

The distance between the inner edges of the front fork tips must be no more than 0.105 m, between the inner edges of the rear fork tips no more than 0.135 m;

A vertical line drawn through any point on the frame of the bike G must not be more than 0.15 m in front of a vertical line that runs through the centre of the front wheel B.

The diameter of the wheels of bicycles, except for BMX sport bikes, must be at least 0.49 m and no more than 0.7 m including the tyre. BMX sport bikes must have a wheel diameter of at least 0.49 m and no more than 0.5 m. The wheel diameter of transport bikes for children must be at least 0.3 m and for children at least 0.4 m.

Parametric model of the frame is created using Solidworks computer program (fig.3). The parametric trivimetric model of the bicycle frame is created with this layout.

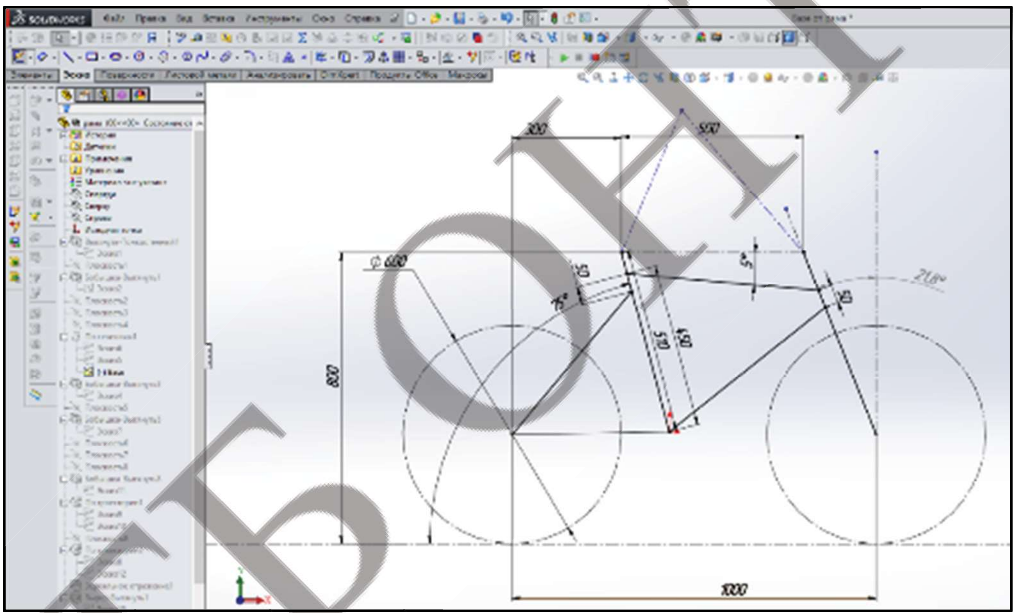


Fig. 3. - Parametric design of a bicycle frame in Solidworks

3.2. Influence of bike design parameters on bike ride

The main design parameters of the frame and their influence on the performance of the bike are described below.

The wheelbase is the distance L between the front and rear wheel axles of the bike. It has a great effect on the bike's handling and is one of the most important characteristics that affects its manoeuvrability and handling. Short wheelbase bikes are more manoeuvrable and long wheelbase bikes make for a more comfortable, forward-looking and controllable vehicle.

The base length affects manoeuvrability. The greater this distance, the more radius must be set when turning (manoeuvrability is reduced), the same reason for increased stability.

Figure 4 shows a checklist for determining the steering angle of a bicycle for different wheelbase lengths. Let's look at the boundary cases where the rotational gradient of the front wheel (it should be noted that the gradient of the handlebar and wheel can be different values due to the handlebar grip) is 0° and 90°. In the first case, the radius of the stake describing the bicycle is of an inconsistent value. In the second case, the stake can be drawn through the 2 points where the bike touches the

ground. For the front wheel, the ratio at the point is identical to the standard centre line of the front wheel. The minimum turning circle of the bike is then half the length of the wheelbase, i.e. 0.5L.

Let us consider the relationship between the radius of rotation and the angle of rotation α of the front wheel. Let's create a block with the centre at the origin of coordinates (point O) and radius R equal to the radius of rotation. At one of the points on the circle, locate a point that conditionally corresponds to the torsion of the rear wheel of the bicycle (point C). From point C, a chord of length L, i.e. the length of the wheelbase, is drawn. The point B, which corresponds to the contact point of the front wheel, marks the point where the chord intersects the stake. The tension to the stake at point B coincides with the front wheel's tension. The length of side OBC=OS=R can be found in the tricycle OC, which is rectosecondary. Thus, radius of turn is equal to $R = \frac{L}{2\cos(2\alpha)}$.

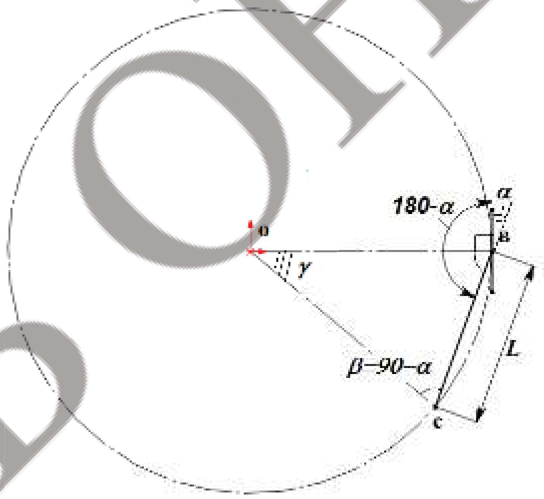


Fig. 4- Exercise for determining the bicycle's turning radius for different wheelbase lengths

The radius of the bicycle's turning circle is proportional to the length of the wheelbase and wrapped in proportion to the cosine of the front wheel's understeer.

Let's analyse how the bike's kerb endurance Δ influences the bike's controllability (Fig. 5). Kernel grip Δ influences the way the bike reacts to a turn. The shorter the grip, the more manoeuvrable and less stable the bike. Point 1 (boundary point of the handlebar) in Fig. 5 will travel a greater distance when the kerm is turned by α the greater the Δ. Therefore, point 1 will follow a path equal to the sum of the length of the arc from the bend α along the radius Δ and the length of the arc from the bend α along the radius 1/2, where 1 is the length of the handlebar.

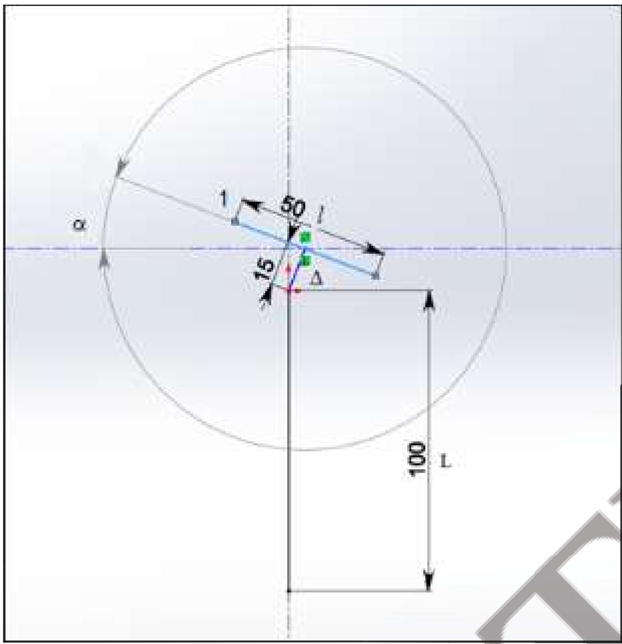


Fig. 5 - Impact of the wheelbase and the arm length on the steering angle

The position of the carriage affects the clearance between the ground and the obstacles on the road and the lower leg position of the rider, the position of the centre of gravity and the stability of the ride.

The lower carriage gives more stability, allowing for easier gimbal operation, but with a greater risk of the pedal catching in the ground. The higher carriage gives more clearance, allowing for easier rotation, but with less stability because the centre of gravity of the burner is displaced.

The shorter rear frame rim gives the rear wheel more contact with the ground and less slippage. As well as the sidewall of the tailpipe, that is, the sidewall between the tailpipe and the line parallel to the ground. A smaller value, an ice bend, causes the rider's weight to be shifted to the rear wheel and increases torque, but reduces speed. A steeper cushion moves the rider's weight forwards, forces the suspension fork to work and ensures a higher sitting position for quick pedalling. The smaller the cushion, the closer the centre of gravity of the bike with the rider to the rear wheel, the greater the alignment (ice cushion). The handlebar grip is measured from the handlebar or head tube to a line parallel to the ground. A slimmer grip allows for smoother control of the bike. A steeper grip is more responsive to manoeuvres. But turning the kernel is also affected by other factors, such as the length of the gauge and the length of the kernel, the clearance and the visibility of the forks.

The steadiness of steering is influenced by the nature of the cyclist's steering, as inertial forces cannot be ignored. The greater the wheelbase, the more stable the ride, as the turning angle is smaller and the less inertia. The centre acceleration is radially directed to the centre of the stake. The greater the radius of rotation, the lower the acceleration.

3.3 Conclusions

To investigate the bicycle frame model, we created a three-dimensional model (Fig. 6) of the bike in SolidWorks 2014 [3, 4].

Figure 6 - Trivimirnaya model of the own bicycle

This bicycle is classified as a road bicycle and has a frame of open structure, with the head tube close to the frame and with a curve closer to the seat tube.

The bicycle (Fig. 7) consists of a frame (6) to which the wheels (4,2) are attached, a frame (1) with a fork of the fork that turns the front wheel (2), pedals on rods (5) and a seat (3). The pedals rotate the wheel via a lancet transmission, a bicycle transmission is used to change the speed of the bicycle, which is a set of various diameters of sprockets.

Figure 7 - Bicycle parts

We can analyse the bicycle frame structure (Fig. 8.) It consists of an upper tube (6) - we don't have it here because the bike is a female model, lower (4) and seat tube (2), upper (1) and lower (3) trunk legs, a head tube (5).

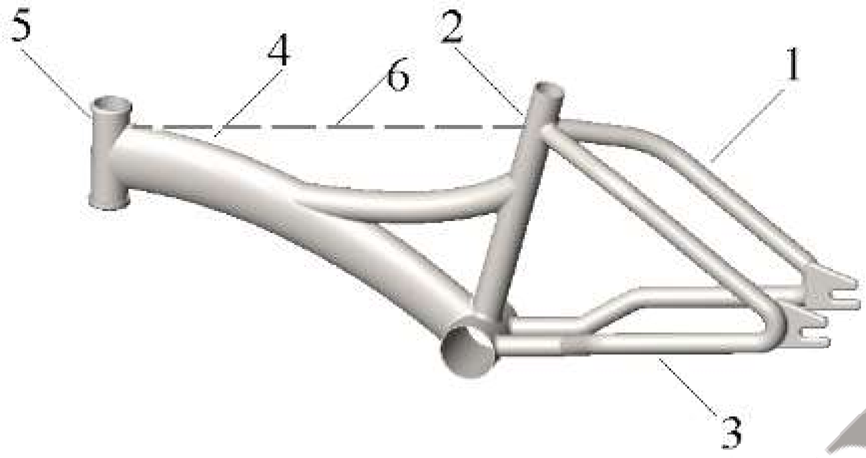


Figure 8 - Bicycle frame

The bicycle frame construction is often a combination of round or elliptical metal tubes.

Let's analyse how the orientation of the pipe cut influences its strength and stiffness properties. For this purpose, we will consider a test problem, a cantilever beam of rectangular crosscut will be subjected to a force which causes bending of the beam in different directions.

The basic variant is a square cut, side length 10 mm, girder length 100 mm, load 700 N (Fig. 9). Let's calculate the effect of positioning two squares of 10 mm side width in horizontal and vertical direction on the girder joint with the same other parameters.

Calculation was performed using SolidWorks Simulation package, which implements the method of joined elements. Accuracy of obtained results is achieved by solving this problem using analytical methods, the difference in results does not exceed 5%.

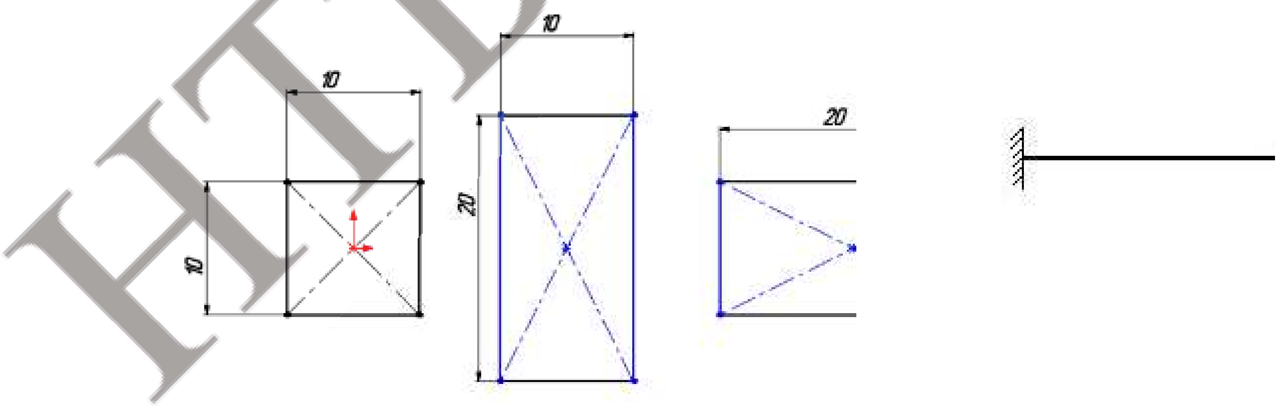
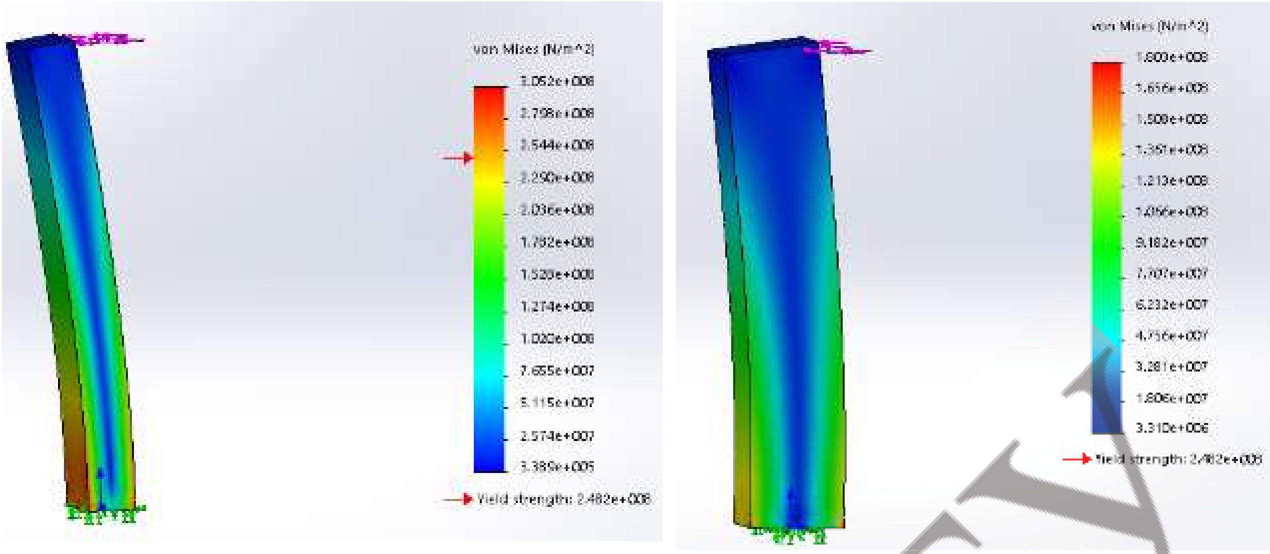


Figure 9 - Revision and calculation scheme of the test problems

The results are shown in Fig. 10, which shows that locating the found side of the rip perpendicular to the acting force increases the stiffness and strength of the beam, but the greatest effect is achieved by locating the found side of the rip parallel to the line of action of the applied force.



a) Cutting dimensions 10×20 mm b) Cutting dimensions 20×10 mm

Fig. 10 - Influence of intersection orientation on girder loads

The shape of the beam and the material of which it is made have a great influence on the strength of the beam. The higher the overlap along the force line, the stronger the girder is. This is why the profile of the bike's lower tube is shaped like an elipse, with the longest part of the tube vertical.

3.4. Frame calculation

To obtain a complete picture of the distribution of loads in the structure, we carry out the frame calculation. We use SolidWorks Simulation engineering analysis package. The dimensioning scheme is shown in Fig. 11. The frame is symmetric, that is why half of the model is used to reduce the calculated complexity. The action of the other part was replaced by the boundary conditions of symmetry. At the point where the steering tube is connected to the steering fork, the boundary conditions - no radial displacement - are imposed. At the point where the rear wheel fork is coupled with the rear wheel axle, boundary conditions are imposed - no radial movement. At the point where the seat tube is connected to the seat, a load of 700 N is applied from the cyclist's weight.

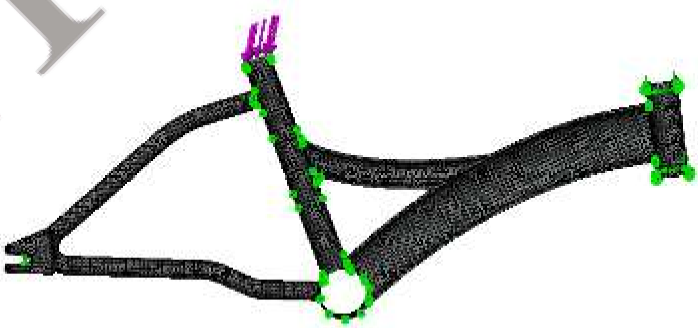
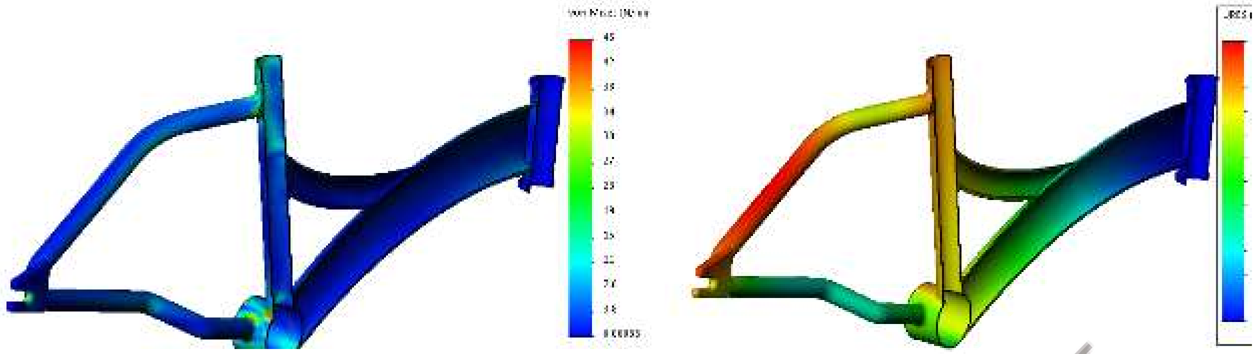


Fig. 11 - Stitching of frame end pieces (Size 5 mm)

Calculations have been carried out with different sizes of the laminated elements and have shown sufficient accuracy of the results obtained. The error does not exceed 15%.

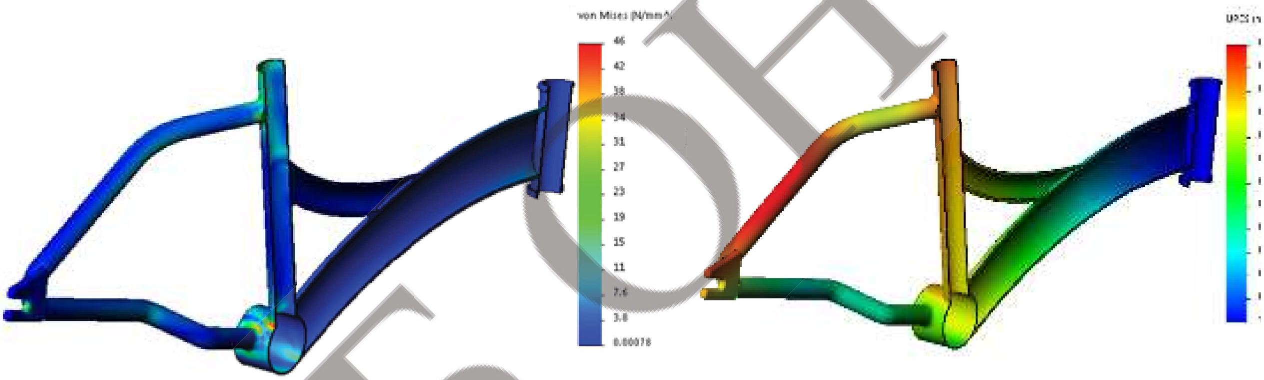
Fig. 3.7 and 3.8 show the results of calculations of the stress-strain state of the frame made of cheap structural carbon steel 3 and aluminium alloy 6061.



a) tension b) relocation

Fig. 12 - The stress-deformed state of the frame in steel 3

The weight of the frame made of steel is 4 kg. The tensile strength [5] for this steel is 195-235 MPa. The maximum frame load is 45 MPa which is localized at the junction of the lower and middle pipes. It can be concluded that the low quality of welding of these pipes can lead to a decrease in the strength of the frame, the appearance of cracks, etc.



a) tension b) relocation

Fig. 13 - The stress-deformed condition of the frame with aluminium alloy 6061

The frame made of aluminium alloy 6061 has a mass of 1.4 kg. The plinth strength for this alloy [6] is 275 MPa, the maximum load did not change at all - 46 MPa. The difference in loads is insignificant but the plinth strength of the aluminium alloy of 275 MPa is even higher than that of carbon steel 195-235 MPa.

The displacement of the frame points has decreased from 0.06 mm to 0.2 mm. This means that the aluminium frame is less rigid, but still sufficiently strong. The maximum displacement of points is at the upper strut of the tricycle

3.5 Summary of the section

A frame made of aluminium alloy 6061 and carbon steel 3 has been dimensioned. The frame in aluminium will be less than 2 times smaller than that in carbon steel. The stiffness of an aluminium frame is 3 times less than that of carbon steel. The maximum stresses for both frames are localized at the connection point of the lower and middle pipes, so the strength of the frame is greatly influenced by the quality of welding of the frame elements. The maximum load for both frames is about 45 MPa at interval of plinth for steel 195-235 MPa, for aluminum alloy 275 MPa. The disadvantage of the 6061 alloy frame is its high price.

IV. RESULTS

The main scientific findings:

1. The radius of the bicycle's turning circle is directly proportional to the length of the wheelbase and is turned in proportion to the cosine of the front wheel's understeer.

2. Gain Δ affects how the bike reacts when turning. The shorter the grip, the more manoeuvrable and less stable the bike is.

3. The lower carriage gives more stability, allowing for easier gimbal operation, but there is a greater risk of the pedal catching in the ground. A higher carriage gives more clearance, which allows for easier rotation, but less stability.

4. The seat tube bend shifts the cyclist's weight and influences the wheel alignment parameters.

5. The smaller handlebars allow for smoother handling of the bike.

6. To increase strength, the largest dimension of the frame lower pipe cross-section must be vertically aligned. The higher the cut, the stronger the girder.

7. The strength analysis of a steel 3 frame and an aluminum 6061 frame showed that the strength of the aluminum frame is reduced by a factor of 2 as compared to the steel frame, the level and localization of loads remains at the same level, but the stiffness is reduced. The price of an aluminium frame is up to 10 times higher than a steel frame.

V. CONCLUSIONS

In the course of the work, a parametric model of the bicycle frame was developed; the influence of the design parameters of the bicycle on its handling and ergonomic properties was investigated; a trivimetric model of the bicycle and its frame was developed and the influence of its design parameters on its strength was analysed.

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