Further Study on an Electric Bike Using a Cycling Posture Analysis, Universal Design, And Finite Element Simulation

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Abstract

The NgebUTS electric bike is one of the vehicles developed by the Sumbawa University of Technology that makes this bike one of the innovations in providing environmentally friendly transportation facilities. Riding the NgebUTS NTB 1 electric bike for an extended period can cause health problems such as Low Back Pain. This study aims to obtain a good evaluation and recommendation for riding an electric bike NTB 1 and a design for an NTB 1 racing electric bike that is more comfortable and safe. The NgebUTS NTB 1 electric bike development uses a Universal Design approach, an analysis of riding posture using the REBA method, and a strength test on the Frame using a simulation finite element method. As for the results of cycling posture analysis, lower cycling postures are better in the form of an angle body recommendation for the neck, torso, upper arm, forearm, and foot are 0°, 0°, 20°, 94 °, and 70°. These are obtained from changes in a bike frame by shortening the size of the bike and modifications to the handlebars by increasing that size. The test results on a bike frame with finite element analysis obtained a displacement value of 0.087 mm and a safety factor value of 4.157 ul, which means the mainframe prototype design is solid and safe to use. With the development of the NgebUTS NTB 1 electric bike, it is hoped that bike users can feel comfortable and secure, reducing the injury risk.

Keywords
finite element simulation, cycling posture, electric bike, universal design.

1. Introduction
Transportation is an effort to transport and carry goods from one place to another (Tseng et al., 2005). Transportation progress shows increased speed, loading capacity, and a transportation infrastructure network that can reach all parts of the region and between regions (Childress et al., 2015). In addition, the increased mobility of people and goods positively contributes to regional development. However, the increasing number of motorized vehicles used by the community produces exhaust gases which cause increased air pollution. Therefore, several countries have begun to switch to environmentally friendly human-powered transportation modes called bikes (Suhardi et al., 2015; Priadythama et al., 2016).

Sumbawa University of Technology (UTS) is one of the universities in Central Indonesia, especially in West Nusa Tenggara Province, which is currently developing environmentally friendly bikes. Through a campus-owned business entity and in collaboration with small industries (IKM), UTS has succeeded in developing an electric bike called NgebUTS. This NTB 1 electric bike has several types, one of which is the NTB 1 electric bike which can be seen in Figure 1. NTB 1 is a male electric bike with a battery capacity of 48V/16Ah and can be used for up to 30 km without using the pedals. The maximum distance can reach 50-60 km if pedals are used.

Figure 1. Electric Bike NgebUTS NTB 1

The NTB 1 electric bike is very suitable for use as a daily vehicle because this bike is environmentally friendly and does not emit exhaust gases. However, the current NTB 1 electric bike is less comfortable when used, such as the saddle size being too small and the pedals being too far away. In addition, the distance between the handlebars and the saddle is quite far, so the cyclist's back will feel sore when cycling the bike. Ergonomic body position due to inappropriate bike size causes low back pain (Vismara et al., 2010). Low back pain is characterized by pain and stiffness in the spine (Story, 2011). The cause of low back pain is the position of the back or posture when driving that is too bent. Therefore, the NTB 1 electric bike needs further study to overcome the inconvenience problem.

In solving this problem, several methods were used. Cycling posture analysis was carried out using the (Rapid Entire Body Assessment) REBA method to use body posture while cycling. The evaluation results determine which parts of the bike need repair. Furthermore, the Universal Design approach is applied to the design of the NTB bike design. The use of universal design is intended so that all users can use the designed bike without the need for adaptation or special design (Hignett and McAtamney, 2000). Next is the finite element simulation method, which is used to validate whether the bike frame design is safe. Furthermore, the work posture analysis is carried out again to evaluate whether the design development that has been made can reduce the risk of the cyclist's posture. It is hoped that with the development of the NTB 1 electric bike, a bike design that is more comfortable and safe when used is obtained.

1.1 Objectives
This study aimed to evaluate the ngebUTS NTB 1 electric bike and recommendations for good working postures for ngebUTS NTB 1 racing electric bicycle riders and to obtain a design of the NTB 1 BUTS electric bicycle which is more comfortable and safe when used.

2. Literature Review

2.1 Cycling Posture Analysis
Work posture is the attitude of the body when work. Different work attitudes will produce different strengths. When Working postures are designed to reduce the incidence of musculoskeletal injury (Sari et al., 2018). The data that will be observed on the cyclist's posture is taken using the data contained in the Rapid Entire Body Assessment (REBA). REBA is used to assess work positions such as the neck, back, arm, wrist, and leg posture (Hignett and McAtamney, 2000). The data to be observed is taken using the data contained in the Rapid Entire Body Assessment (REBA).

The purpose of the REBA analysis is to measure the risk of injury to the cyclist's body to work posture and to place the assessment score needed to reduce the risk of injury to the cyclist's body. The results obtained from the REBA analysis are used to determine the distance between the position of the cyclist and the parts on the NgebUTS NTB 1 electric bike.The following is the REBA table used when testing the cyclist's posture .(Figure 2)

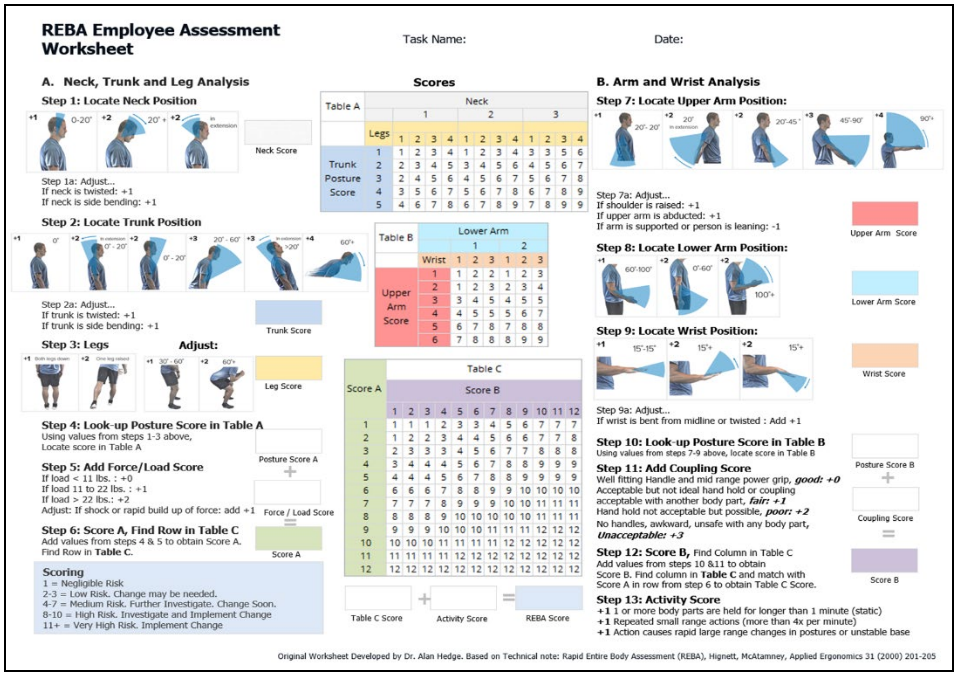


Figure 2. Rapid Entire Body Assessment (REBA) Worksheet

2.2 Universal Design

Design development with a universal design approach is a method that benefits everyone without the need for adaptation (Story, 2011). By using this method, it is hoped that the NgebUTS NTB 1 electric bike can meet the needs of all people. Universal design has the following main principles (Story, 2011):

1. Equality in use
   That is a design that can be used for all people or users with various abilities and aims to provide facilities that can be used by all users
2. User flexibility
   The principle is flexible and can accommodate various circumstances and individual abilities without physical limitations, age ranges, or gender.
3. Simple use
   Namely the use of an easy-to-understand design, which aims to eliminate unnecessary complexity.
4. Clear information
   That is to provide information to users in a way that is easier to understand in conveying information or instructions.
5. Tolerating mistakes
   That is to minimize the harmful harm from intentional and unintentional actions and aims to minimize the emergence of danger and errors.
6. Reduce physical effort
   That is, it can be used comfortably and untiring so that it is more efficient
7. Provide size and space for approach and use
   With appropriate size and space provided for approach, reach, and usable use without size limitation

2.3 Finite Element Simulation

The finite element analysis method is one of the methods used to analyze the strength of a structure which is an important part of the design and workflow in product development. Strength analysis is carried out by theoretical formulation using engineering and structural mechanics. In analyzing a structure to obtain from a problem. This technique is a new approach made possible by advances in computers and planning methods using computers in recent times. The element can be a line, a triangle, or any geometric shape. The member to be analyzed is first divided into multiple finite elements (meshing), which may be of several different sizes. Starting from the design of the structure, then carried out the imposition and determination of regional boundaries and constraints (Priadythama et al., 2016).

At this stage, testing is carried out using finite element Simulation. The simulation results show whether the results on the mainframe of the bike can be used safely. The thing that needs to be considered in determining better results is the security parameter in the main framework test results. The safety parameter is influenced by the value of the safety factor and the value of displacement. The design is safe if the result of the safety factor is more than 4 ul (Juvinall & Marshek, 2011) and the safe limit of the permissible displacement result is less than 0.3 mm (Izumi et al., 2005).

3. Methods

This research was conducted in 5 steps.

Step 1: The observation process. At this stage, observations were made of the problems that occurred in the use of NgeUTS NTB 1 electric bikes. These problems will form the basis of this research.

Step 2: Working Posture Analysis: assessment of working posture while riding the NgeUTS NTB 1 electric bike using the REBA method.

Step 3: The next stage is the development of a design with a universal design approach, which is a method that benefits everyone without the need for adaptation. By using this method, it is hoped that the NgebUTS NTB 1 electric bicycle can meet the needs of all groups. According to Story (2011), Universal design has main principles, namely:

1. Equality in use
2. User flexibility
3. Simple usage
4. Clear information
5. Give tolerance to mistakes
6. Reducing physical effort
7. Provide size and space for approach and use

Step 4: Then a finite element analysis is carried out to test the strength of the frame with stress analysis to obtain the strength of the UTS electric bicycle frame. Design and testing were carried out using Autodesk Inventor 2017 software.

Step 5: A final REBA evaluation is carried out to find out whether the designed bicycle design can minimize the risk of illness in UTS electric bicycle users.

4. Results and Discussion

4.1 Early Cycling Posture Analysis

The initial REBA analysis using the NgebUTS NTB 1 electric bike was observed to determine the angle of the body posture of an object. The angle of the cyclist's posture can be seen in Figure 3.

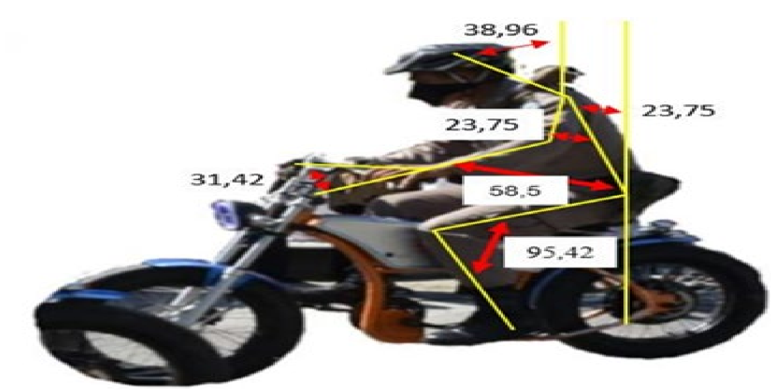


Figure 3. Body Lines and Angles of The Cyclist Using NgebUTS NTB 1

The results of the REBA calculation using the electric bike NgebUTS NTB 1 that have been carried out can be seen in the REBA worksheets in figure 4. The results of the calculations in the REBA worksheets, the final score for using an electric bike NgebUTS NTB 1 is 5, where the REBA score indicates that it has a medium risk and needs to be investigated further and changed immediately. (Figure 4)

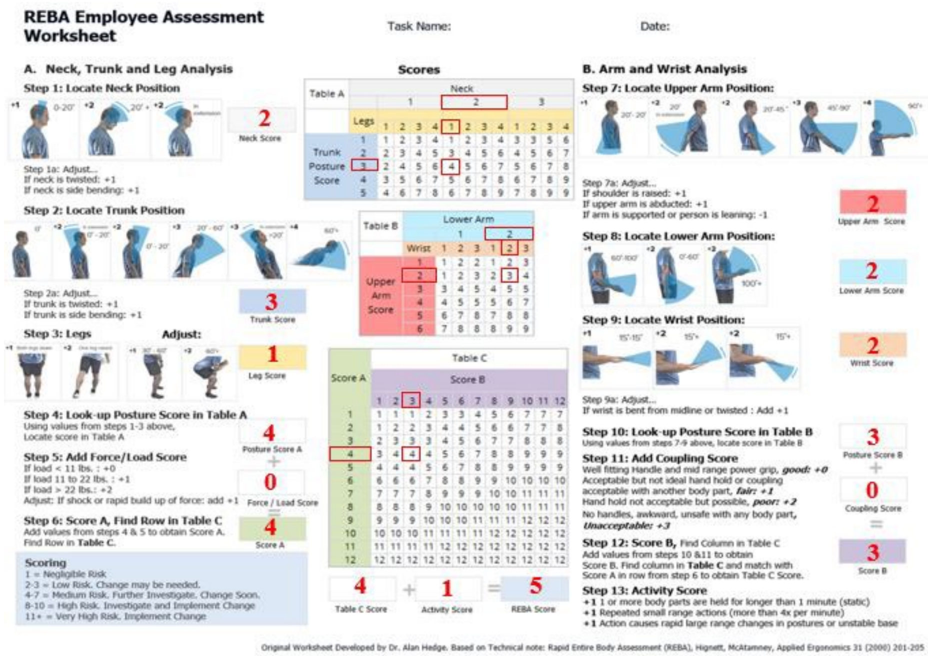


Figure 4. REBA Worksheets of The Cyclist Using NgebUTS NTB 1

4.2 Electric Bike Development

The development of an electric bike design is carried out using a universal design approach by taking into account the following principles.

1. Equality in use

   On this principle, the designs that have been made can be used by everyone. The data used in the design of the NTB 1 electric bike in Indonesian anthropometry that can be seen in Table 1.

Table 1. Indonesian Anthropometric Data for Equality in Use Principles

Data	Criteria
Tribe	all tribes
Gender	all gender
Age	17-45

www.antropometriindonesia.org

2. User flexibility

   In this principle, the user's flexibility data is obtained from www.antropometriindonesia.org by taking the height of the vertebrae, and the 50^{th} percentile or average size.
3. Simple use

   On this principle, the design of the bike made can be understood when using a bike. In general, bike elements have a simple design so that the cyclist can ride easily.
4. Clear information

   In this principle, providing supporting information contained in the bike so that it is easy to understand. The electric bike speedometer serves as a tool for information to the cyclist such as bike speed, battery capacity, indicator light, and distance traveled.

5. Tolerating errors.
   Bicycle design is carried out to minimize the danger to the cyclist due to an accident, whether intentional or not. Such as the selection of good material components.
6. Reduce physical effort
   On this principle, existing facilities can be used efficiently and comfortably in all conditions.
7. Provide size and space for approach and use.
   In this principle, providing measurements by taking data with an approach to posture and size on cyclists.

Here is the part change design on the NgebUTS NTB 1 electric bike that can be seen in Figure 5.

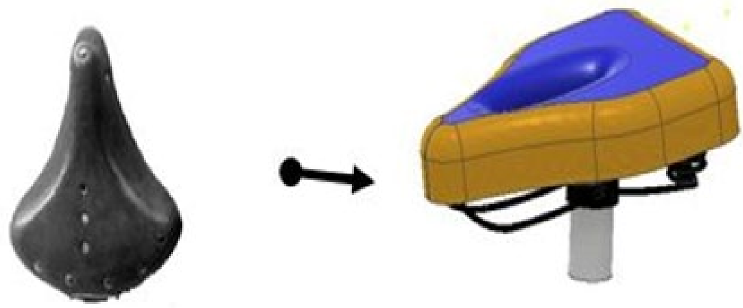


Figure 5. Saddle Change Recommendation in Electric Bike NgebUTS NTB 1

The problem with the saddle is that the saddle size is small and thin, so the cyclist is uncomfortable when sitting, so improvements are made in the form of appropriate geometry changes. The right-angle position on the saddle can prevent numbness between the hips or cramps in the upper body (Valachi and Valachi, 2003). The proposed saddle is made differently from a bike saddle in general.It is done to prevent the cyclist from numbness between the hips or cramps in the upper body due to the small and thin seat. In the Saddle design, the bike is given a hole to provide good air circulation for the groin. The wind can rise and provide comfort to the thigh and its surroundings (Chen and Chao 2021). Part of the anthropometry used in designing the saddle is the hip width. The size of the hip width is used as the width of the saddle design; the percentile used is the 50th percentile, and the thickness of the saddle is 5 cm. The saddle thickness is used so the cyclist feels comfortable when riding a bike. The 50th percentile is used based on the principle of universal design, namely fair use. The next component that makes changes is the handlebars which can be seen in Figure 6.

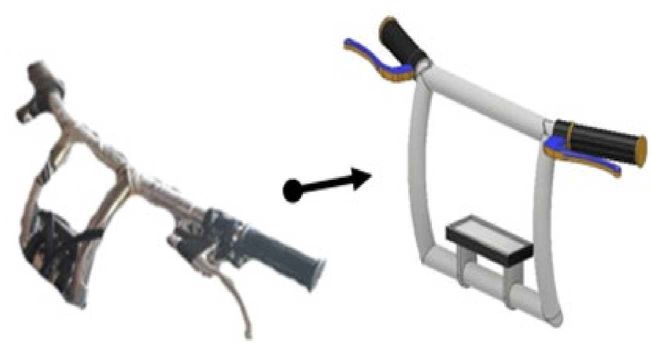


Figure 6. Handlebar Change Recommendation in Electric Bike NgebUTS NTB 1

The design concept of the handlebar is unchanged from the shape of the handlebars on the initial bike design. The thing that distinguishes it is the size of the initial handlebars and the proposed handlebars that have been designed. The initial handlebars have a height of 15 cm and a length of 67 cm; the proposed handlebars have a height of 20 cm and a length of 40 cm. The change is based on anthropometric measurements of shoulder width. The size of the shoulder width is used as a reference for making the proposed handlebar length, and the percentile used is the 50th percentile with a size of 40 cm. The 50th percentile was chosen based on the principle of universal design, namely fair use. The 50th percentile in the design is based on the average human size. Changes in the height of the handlebars from 15 cm to 20 cm due to the position of the arm using the handlebars are unrecommended. The angle of the forearm of the user is 58.57^{o}. In posture analysis, angles of 0^{o} to 60^{o} and 100^{o} upwards across the forearm are unrecommended (Midlesworth, 2020). The recommended angle is 60o to 100o. Therefore, improvements were made to the handlebars so that the angle of the cyclist's arm is large so that the cyclist feels comfortable while riding. The next component that makes changes in the Frame can be seen in Figure 7.

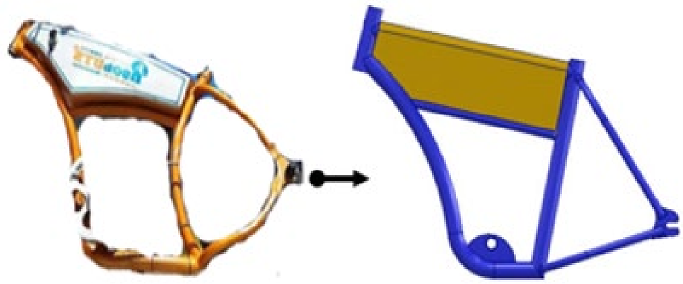


Figure 7. Recommendations for changing the Frame on the NgebUTS NTB Electric Bike 1

The specification changes to the Frame are in the form of size changes. Size greatly affects the comfort, effectiveness, and efficiency of cyclists against the designed Frame (Laios and Giannatsis, 2010). The development of this component uses universal design principles as a reference in the form of equitable use, flexibility in use, and size and space for approach and use. The size change is found in the length of the mainframe from 900 mm to 780 mm. Changes also occur in height from the seat tube to the bottom bracket. The height from the seat tube to the initial Frame of 500 mm changed to 430 mm.

4.3 Test Results

The test was carried out only on the mainframe design on an electric bike with calculations to obtain the weight of the cyclist supported by the bike frame obtained from Anthropometric data with the age of 17-45 years, the age range used was due to the age range of adults who are still actively using bikes. The size of the body segments used in this study was obtained from www.antropometriindonesia.org. After the data is obtained, the cyclist's weight is calculated using the Body Mass Index (BMI) formula of 30 kg/m². The calculation is described by equation 1.

Height of Cyclist (TB) = 177,34 cm = 1,78 m
Weight of Cyclist (BB) = 30 x TB x TB (1)
= 30 kg/m² x 1,78 x 1,78
= 95,052 kg

The proportion of the cyclist's body weight on each body segment used in this study corresponds to the anthropometric percentage of the human body in the book Biomechanics and Motor Control of Human Movement by Winter. The load can be calculated using adult body weight data described in equation 2.

Body Load = Weight of Cyclist (BB) kg x Gravitation (g) m/s² (2)
= 95.052 kg x 9,8 m/s²
= 9312 N

The body load of the rider that has been obtained is then distributed to several body parts, such as the head, upper arms, forearms, palms, back, hips, thighs, calves, and soles of the feet. Each of these parts has it is respective load proportions according to the anthropometric percentage, which can be seen in the Table 2 .

Table 2. Proportion of Load on Body Segments

No	Body Part	Percentage	Force (N)	Forced of Part (N)
1	Head	8.40%	931	78
2	Upper Arm	5.60%	931	52
3	Forearm	3.40%	931	32
4	Palms	1.20%	931	11
5	Back	25%	931	233

No	Body Part	Percentage	Force (N)	Forced of Part (N)
6	Hip	25%	931	233
7	Thingh	20%	931	186
8	Calf	8.60%	931	80
9	Feet	2.80%	931	26

Testing on the NgebUTS NTB 1 electric bike needs to be done by determining the elements on the mainframe and the dimensions of the mainframe first to the point of mass of the cyclist's body. The following is the location of the mass point concerning the two nearest fulcra, which can be seen in Figure 8.

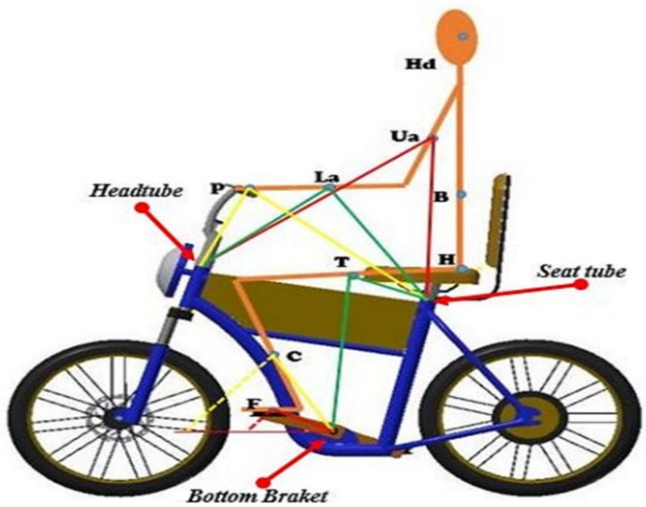


Figure 8. Point of Mass Against 2 Supports

After knowing the elbow point on the forearm,, calculate the vertical and horizontal force from each body obtained, such as the bottom bracket, Headtube, and Seat tube.

The following is a summary of the styles of bicycle elements which can be seen in Table 3

Table 3. Vertical Force And Horizontal Force On The Frame

Part	Vertical Force (N)	Horizontal Force (N)	Part
Fbb (Bottom bracket)	239,84	47,45	Fbb (Bottom bracket)
Fht (headtube)	62,8	69,44	Fht (headtube)
Fst (seat tube)	628,29	207,96	Fst (seat tube)

The following are the Vertical and horizontal forces on the Frame which can be seen in Figure 9.

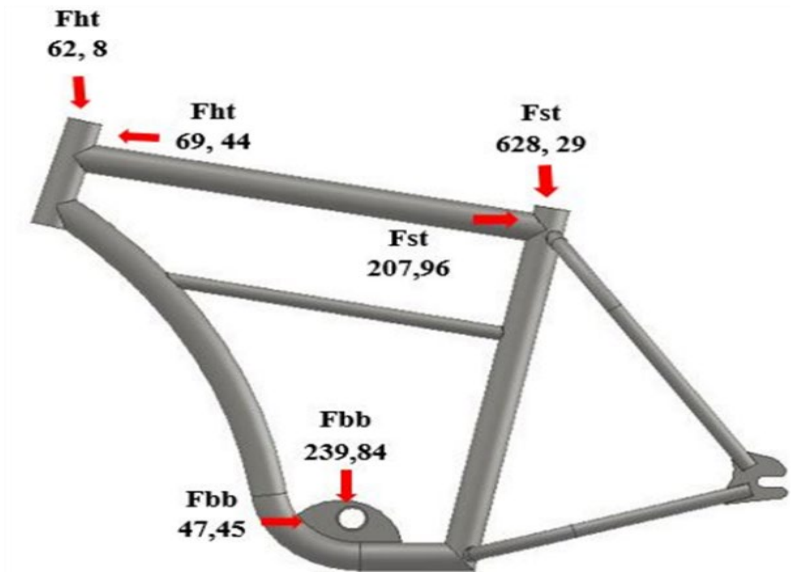


Figure 9. Vertical Force And Horizontal Force On The Frame

The vertical reaction force is a force whose direction is perpendicular to the horizontal plane on the mainframe of the bicycle. This force comes from the magnitude of the moment on each bicycle support and bicycle load. The amount of the cyclist's load resting on the mainframe supports is then calculated using the moment calculation to determine the resulting action force. The action force that arises is found on the part that supports the rear wheel (Rbv) , and the front wheel (Rav) can be seen in Figure 10.

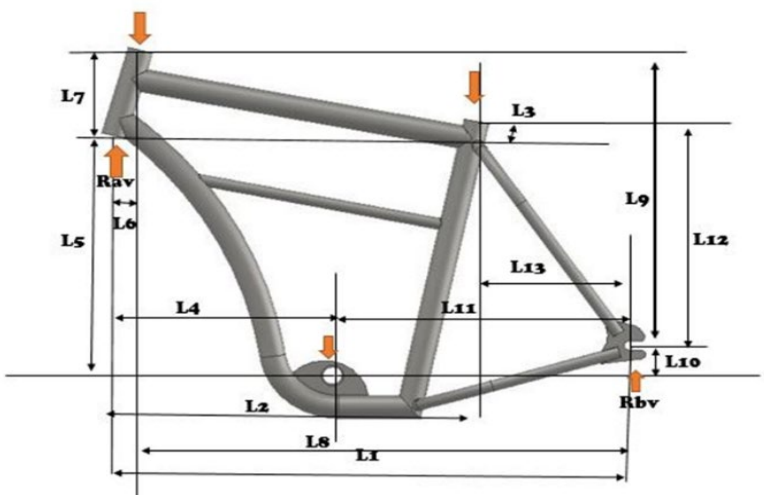


Figure 10. Vertical Reaction Force

The force resting on the bicycle is then used to calculate the vertical force acting on the front and rear wheels of the bicycle. The calculation of the action force can be seen below.

ΣMa =0
0 = – (Rbv x L1) + (Fst x L2) + (Fst x L3) + (Fbb x L4) – (Fbb x L5)
+ (Fht x L6) - (Fht x L7) (3)
0 = – (Rbv x 0,781) + (628,29 x 0,551) + (207,95 x 0,033)
+ (239,84 x 0,333) + (47,45 x 0,396) + (62,8 x 0,042) - (69,44 x 0,154)
0 = – 0,781 Rbv + 346,187 + 6,862 + 97,848 - 18,790 + 2,637 – 10,693

0,781 Rbv = 424,051
Rbv = 524,959 N
ΣMb = 0
0 = (Rav x L1) - (Fht x L8) + (Fst x L9) - (Fbb x L11) – (Fbb x L10) + (Fst x L13) + (Fst x L12)
0 = (Rav x 0,781) - (62,8 x 0,738) - (69,44 x 0,499) - (239,84 x 0,448) – (47,45 x 0,051) - (628,29 x 0,229) + (207,96 x 0,379)
0 = 0,781 Rav – 46,346 – 34,560 – 107,448 - 2,419 – 143,878 + 78,816
0,781 Rav = (- 177,109)
Rav = 226,772 N

From the calculation of the action force, there are calculation results on the part that supports the rear wheel (Rbv) which is 524,959 N and the front wheel (Rav) is 226,772 N.

The horizontal reaction force consists of horizontal forces from loading, pedaling forces, friction forces, and bicycle chain forces. This force is influenced by the moment force from the rear wheel and the coefficient of friction between the bicycle tire and the asphalt. The coefficient of static friction between tires and dry asphalt is 1.0 (Young et al., 2013). Then the calculation of this frictional force can be seen below.

Fx = coefficient of friction x force Rbv (4)
= 1,0 x 524,959
= 524,959 N

The cyclist's pedaling force is the driving force of the cyclist on the pedal so that the movement of the bicycle is pushed forward. This style is in line with the bicycle frame. The magnitude of the pedaling force (Fp) is directly proportional to the force on the rear wheel (Rbv). The components used to calculate the cyclist's pedaling force are shown in Table 3.

Table 2. Components of Paddle Style

Fx	Friction on the rear wheel of a bicycle	524,959 N
Rgd	Front gear spokes	7,5cm
Rrb	Rear wheel spokes	25,4 cm
Rgb	Rear gear spokes	5 cm

From the table of the constituent components, the bicycle pedaling force is calculated, described below.

$$\text{Fp} = \frac{\text{Fx x Rgd x Rrb}}{\text{Rgb x Ltp}} \quad (5)$$

$$\text{Fp} = \frac{524{,}959\ x\ 7{,}5\ x\ 25{,}4}{5 \text{ x } 20}$$

Fp = 1000,046 N

The bicycle chain force is a force that is opposite to the frictional force of the rear wheel of the bicycle. This force moves the bicycle chain by rotating the bicycle chain, which is 524,959 N. The component that gets this additional horizontal force is the force on the bottom bracket with an initial force of 47.45 N so that the Fbb force becomes 572.409 N.

The Fst force is a force whose magnitude is influenced by the pedaling force of a bicycle vehicle. This force has a value of 1000.046 N, then added with an initial value of 207.96 so that the Fst force becomes 1208.006 N. The following is the overall force received by the bicycle frame summarized in Figure 10.

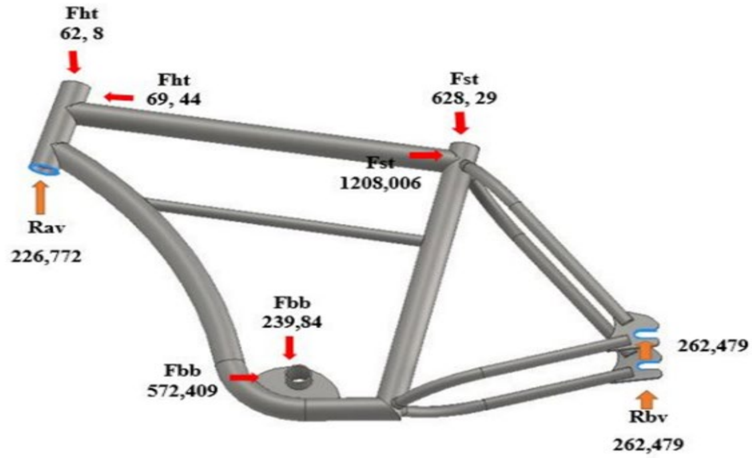
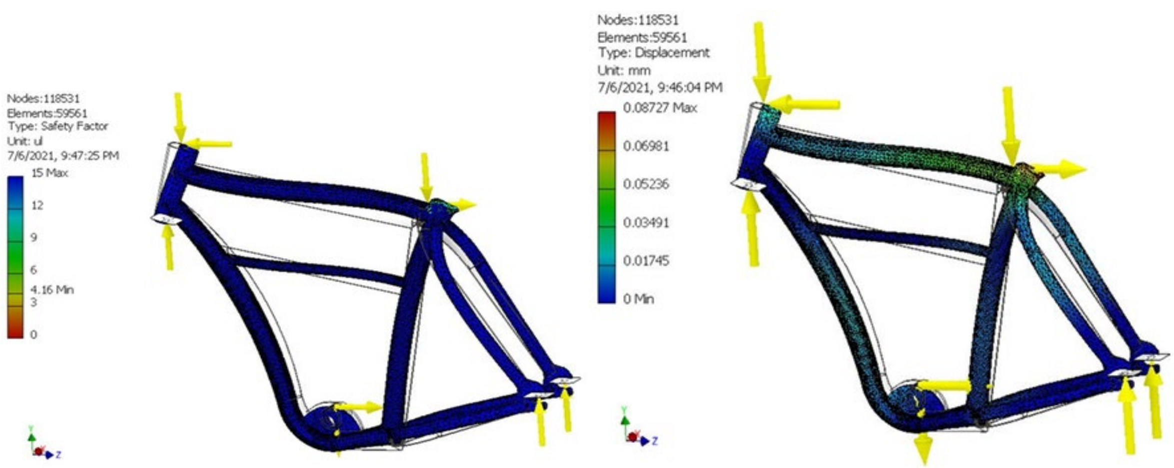


Figure 10. Style on the bicycle frame

The finite element simulation results were carried out by giving the cyclist a load. The load is divided into nine body segments according to the anthropometric percentage of the human body (Winter, 2009). The two closest fulcrums support the load from these body segments to the fulcrum, namely the head tube, seat tube, and bottom bracket. The results of the loading that the mainframe has received are then calculated at each corner of the body and obtained forces in the form of vertical forces and horizontal forces on the mainframe. Furthermore, the pedaling and frictional forces are given because these two forces cause the bike to move. Framework, the next step is a finite element analysis simulation using Autodesk Inventor 2017 software. In the results of the simulation with the loading of 95.052 kg, it was found that the minimum safety factor for the proposed framework was 4.15774 ul, and the results of the framework test were the safety factor value, the results of the Safety Factor simulation that can be seen in Figure 11 (a). In addition to the safety factor, the proposed frame displacement value is 0.0872 mm. The results of the displacement simulation can be seen in Figure 11 (b).



(a) (b)

Figure 11. Test Result of Recommendation Bike Frame for NTB 1 (a) Safety Factor, (b) Displacement

4.4 Final Work Posture Analysis

After the bike design is made, the next step is to calculate the final REBA to determine whether the designed design can reduce the risk of injury to the body while riding a bike. Here is a bike design using a stick diagram with the withdrawal of the angle of the body posture, which can be seen in Figure 12.

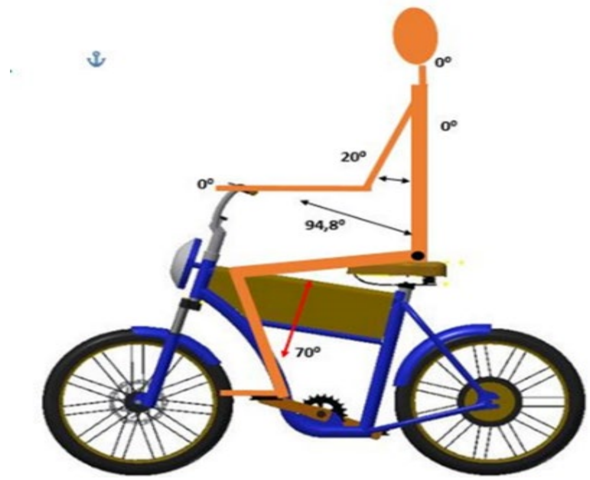
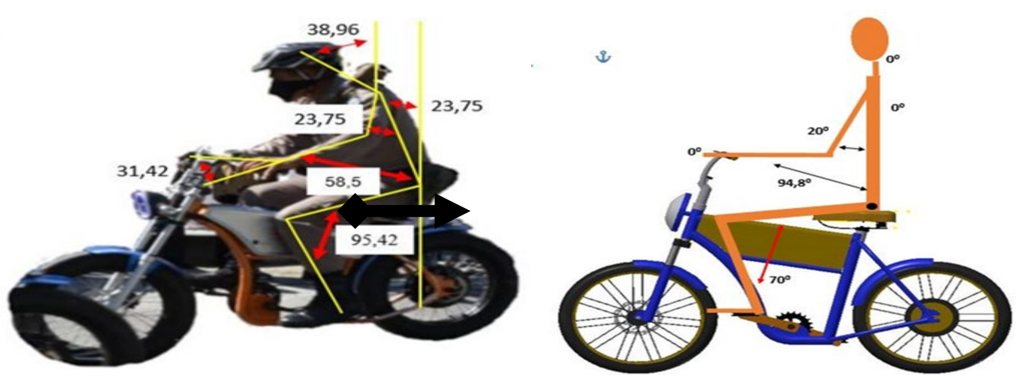


Figure 12. Body Lines and Angles

The results of the REBA calculation using the electric bike NgebUTS NTB 1 that have been carried out can be seen in the REBA worksheets. From the results of calculating the working posture of cyclists using the REBA table, the final score for the proposed bike NgebUTS NTB 1 activity is 2 which has low risk and changes may need to be needed.

5.5 Discussion

The first step is an analysis of the working posture of the NgebUTS NTB electric bike 1 . Cycling posture analysis was carried out using the REBA method to evaluate body posture while cycling. The results of the evaluation are used to determine which parts of the bicycle need repair. Furthermore, the Universal Design approach is applied to the design of the NgebUTS NTB electric bike 1. Universal design is used so that the designed bicycle can be used by all users by using the principles contained in the universal design. Next is the use of the finite element analysis method to get the value of the safety factor and displacement value which is used to test the strength of the mainframe of the bicycle so that the value of the safety factor and displacement value can be known. From these results, it can be seen whether the bicycle frame design that has been made is comfortable and safe to use. Furthermore, the work posture analysis is carried out again to evaluate whether the design development that has been made is able to reduce the risk of the rider's posture. A comparison of the positions of riding a bicycle can be seen in Figure 12



(a) **(b)**

Figure 12. (a) Position of the electric bike of NgebUTS NTB 1, (b) Position of the rider of the designed electric bike of NgebUTS NTB 1

Based on the picture Figure 12 above, it can be seen that the position of the rider using the electric bike design is safer than the position of the rider using the NgebUTS NTB electric bike 1. This can be seen in the results of calculations using the calculations in the final REBA table, the final score using the proposed bicycle is 2 and the initial REBA value is 5.

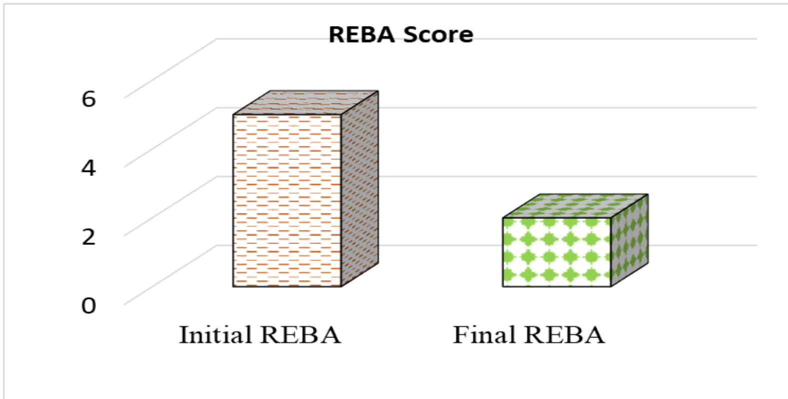


Figure 13. REBA Value Comparison

Based on the picture Figure 13 above, it can be seen that there is a decrease in the risk of injury based on overall body posture using REBA. The risk reduction is from a work posture that has a moderate risk and needs to be corrected immediately (score 5) to a cycling posture that has a low risk (score 2), so it can make the bike safe to ride.

6. Conclusion

The potential for injury to an electric cyclist in West Nusa Tenggara 1 was obtained from an analysis of the cyclist's posture using the REBA table, so the final score for the activity of using a bike was 5 which the REBA score indicates that has a medium risk, it needs to be investigated further and changes immediately. bike development is done to get a safe and comfortable design. development of the NgebUTS NTB 1 bike design in the form of saddles, handlebars, bike frames that are safer and more comfortable when used. Safe can be seen from the value of the safety factor and displacement. A comfortable bike judging by the REBA value. From the results of calculating the working posture of cyclists using the REBA table, the final score for the proposed bike activity is 2 which has low risk and changes may need to be needed. where the value means the posture is acceptable and safe to ride. It is hoped that with the development of the NgebUTS NTB 1 electric bike, bike users can feel comfortable and safe while driving and the risk of injury can be reduced.

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