Design and Development of an O-Ring Shape Bicycle Frame

Ratnamon Rarchiratham[1], Pongtorn Prombut[2] andThanya Kiatiwat[2]*

[1]Master of Engineering Program in Industrial Production Technology
[2]Department of Mechanical Engineering
Faculty of Engineering, Kasetsart University
50 Ngam Wong Wan Road, Ladyaow, Chatuchak, Bangkok10900
*Contact: fengtyk@ku.ac.th, Tel. 0-2797-0999, Fax. 0-2579-4576

Abstract

Bicycles are alternative ways of transportation and exercise for many people, benefit of cycling is good for health, save a space and save money with zero pollution. The problem is it not easy to putting a bike in the trunk of car, carrying it on the train during rush hour, or just storing it in ultra-efficient apartment. O-Ring Shape Bicycle is designed to solve these problems. Concept are foldable light-weight, compact and portable. When folded, the bicycle will be in a shape of simple O-ring and suit for any kinds of transportation even carrying. The design starting with human ergonomics to sync with a cycling position with hands, saddle and pedal positions of the bicycle. Then design the position of the folding parts and locking joints. Power transmission of the bicycle using 2 sets of belt/pulley connecting by a gear coupling. Designing the balance and strength by using static and dynamic calculation to apply fix points, forces, and moments into CAD and finite element models to study the behavior of an aluminum O-ring shape bicycle frame when it is in use condition. The resultswill be used as a guideline for designing the fiber orientation and stacking sequence of carbon fiber composite material to be used in place of aluminum for reducing weight and improving strength of the O-ring shaped frame.

Keywords:Foldable bicycle, O-ring frame, Light weight structure.

1. Introduction

"Bicycle is a human-powered, pedal-driven, single-track vehicle, having two wheels attached to a frame, one behind the other. Bicycles were introduced in the 19th century in Europe and now numbers more than a billion worldwide, twice as many as automobiles. They are the principal means of transportation in many regions. They also provide a popular form of recreation and adapted for use"[1]

The collapsible bicycle is the revolution of bicycle that made for safe a space and easier for carrying around. Existing collapsible bicycles available in the market have not fully met the satisfaction of the present users. For example, their beam structures still come in sizes that are not quite portable. The O-ring shape frame bicycle can make the bicycle become more compact.

There are some conceptual bicyclesuch as a concept design called the "Locust" by Czech designer; Josef Cadek, since 2006[2]. The unique feature of the Locust is its circular frame and overhang mounted wheels that would allow for a more compact and visually pleasing folded state.

In 2012, the Donut folding bicycle concept[3]was released with more compactfolds into a nice round circle that leaves no component exposed. From the handlebars to the pedals, everything is safely tucked away and making it incredibly easy to carry around and store. It also puts the rider in a fairly aggressive position with a low handlebar location.Both design still not work practically,in term of folding, various joints which are not complete joint locking and shows errors in the design of the posture of the cycling. There is no prototype existing and even any research or analysis.

2. Objectives and Boundary

In term of structural design and development needs to design the proper sizes, positions and functions of the bicycle components that fit properly within the O-ring frame in the collapsed position and practical work in cycling position right through the ergonomic cycling position. Design the power transmission system that co-operates with folding system. Then build the elements to 3D CAD.

For durabilityand practicality,this research studies behavior of the O-ring shape frame when under the condition of cycling loading by using static calculation to get to know positions, directions and quantity of loadings, bending forces, moments and shearing forceson O-ring shape frame to apply all of the loading condition onto CAD to compute and analyze by finite element analysis (FEA) method.

The result can be used as a guideline for designing the fiber orientation and stacking sequence of carbon fiber composite material to be used instead of aluminum fordecreasing weight and improving strength of the O-ring shape of bicycle frame.

3. Principle of Bicycle Ergonomics and Designing

3.1 Why O-shape?

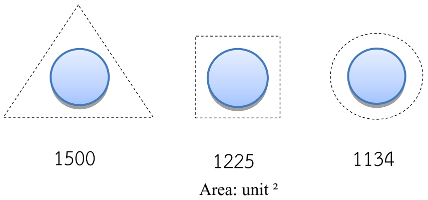

Fig. 1Comparison an areaof a packaging shape

From **Error! Reference source not found.**1 blue circles represent the wheels of a bicycle that need to be packed into some shape, compare with 3 shapes(dashed line);triangle, rectangle and circle. Circular shape is spend less area inside dashed boundary line with 1134 unit^2 which most proper to use as a frame of bicycle.

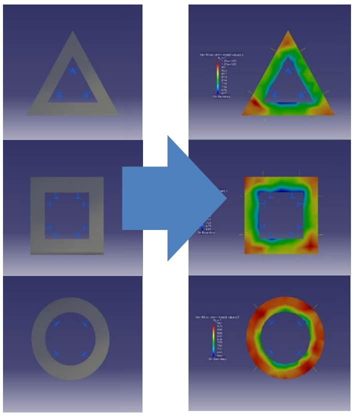

Fig. 2 Comparison strength of each shape

Consider in term of strength, an experimental about stress analysis with a thick surfaces by fix the surface inside each shape and then apply distribute load about 1kN at outside surface of each shape.In order to obtain the stress distribution,let's fix the parameters as show the parameters in **Error! Reference source not found.**1 and lets the stress variable spread by difference shapes.

Table. 1 Parameters of testing strength of the shapes

Fixed	value	unit
Thickness	1	mm
Width	20	mm
Load	1	kN

The stress in circular shape is the most uniformly distributed compare with others as show in **Error! Reference source not found.**2 that the red area is spread all over the circular volume but for rectangular and triangular shape there is a stress-concentration occurs at the edges of these two shapes and this may cause the failure at the edges of the shape when under the load.

3.2 Triangle of cyclingposition

To design a riding position, let's start with a triangle that connect the handlebars, middle of the seat, and the pedal point. The angle of triangle has an effect with the comfort and performance of the bike. For a Supersport, a high seat, low bars and high pedal point the body is pushed forwardfor an aerodynamic flow and to maximize control of the bike at high speeds. Touring cruiser needs a high bar, low seat, and forward pedal point to put body in a relaxed position, but it will not offer as much control for the bike. There are many options in between and making sure thatcomfortable will always give a better ride.

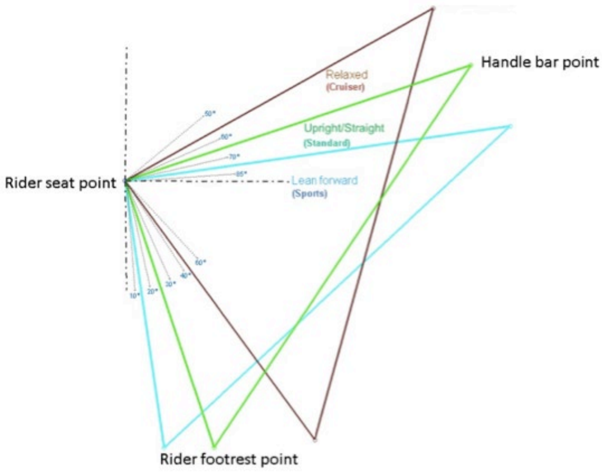

Fig. 3Triangle of cycling position[4]

3.3City bike position

As showed in the Fig.4, thetorso slightly inclined, about 60 to 70° deg. angle toward the ground showing in red lines angle (High handlebar).

The rider advantage is a good view of the traffic and power can be firmly applied to the pedal. While the disadvantages are the arms are often held straight to grip the high handlebars. which leads to cramped shoulders and pain in the hands.[5]

Fig. 4 City bike torso position and angle[5]

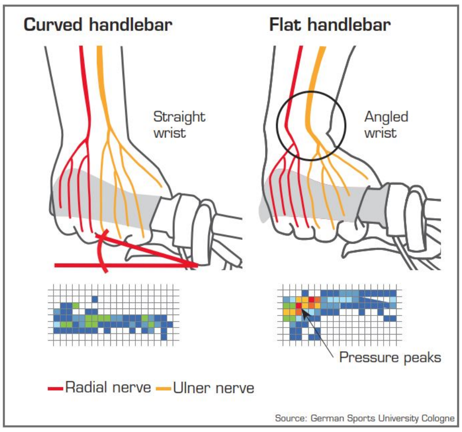

Fig. 5 City bike hand position[5]

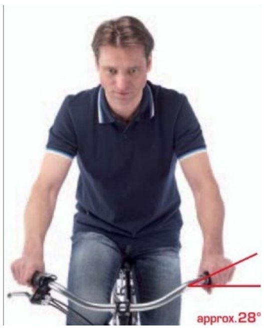

Fig. 6 City bike hand position[5]

In Fig. 5, thebest hand position on the handlebar is when the lower arm and the hand are alignedcontinually straight. In this position, the ulner nerve and the radial nerve run straight, there is no peak of pressure and therefore pain-free.Many sport physicians therefore advocate curved handlebars. The wrist is less stained and the carpal tunnel (the nerve tunnel on the palm side of the hand) is not squeezed.The narrower of the shoulders are the greater of the curvature, the handlebar should be up to 28 degrees (Fig. 6).

3.4Composition and alignment

Extracting3 points; handlebars, middle of the seat and the pedal point fromFig. 4 will get the triangle of cycling position for city bike as show in Fig. 7. The angle of this triangle is 72°and30° means the city bike position is in range of the upright/straight (standard) as define in Fig. 1.

The 2D and design of overall position and function of the bicycleshow in Fig. 8,let's fix the position of the triangle, hide the reference photo of a city bike,then set circular of wheels (outside wheel's diameter is 379 mm. – 16 inch standard bicycle wheel) on the ground then create the circular of bicycle frame then synchronize this 3 circles with folding joint position, this step will get size of the O-ring shape bicycle frame of 619 mm.diameter and 30 mm. thick,fix the position this 3 circles.Then,design the folding hands, stem, and saddle (set its length, folding direction, and locking system. The finished 2D design is showing in Fig. 8. Finally create 3D CAD model and use 3D Mankin (a man with 170 cm. tall) to test cycling posture, Fig. 9.

Fig.7Triangle of cycling position for city bike.

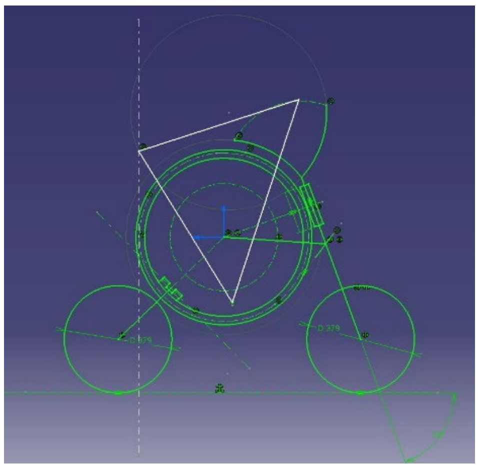

Fig.8 2D placement and folding design.

In Fig. 9, volume of the unfolded is 123.3 x 102.5 x 15 cm. The dimension is not too big that user can drag or carry around easily and not too small, rider can easily balance the weight and not hard to control on a ride.In Fig. 10-11, volume of the foldedis Ø73.5 × 23.5 cm. About the O-ring bicycle frame width,the width of narrowed section of the frame is 7 cm,the actual width of bicycle frame is 13.4 cm. The design of narrowed section as showed in Fig. 11-12is for give way to the legs and also have a benefit for aerodynamics and reduce weight.

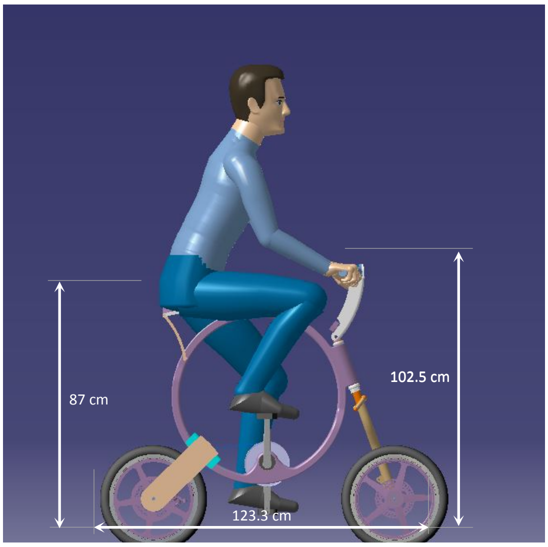

Fig. 9 3D of all components with demonstration Mankin and dimension of unfolded volume.

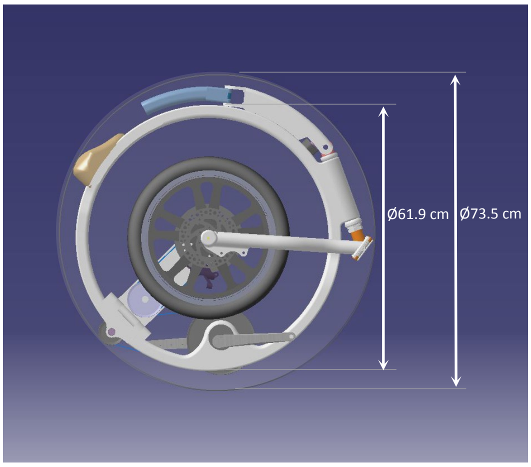

Fig. 103D folded version with dimension of outside frame diameter and packaging diameter.

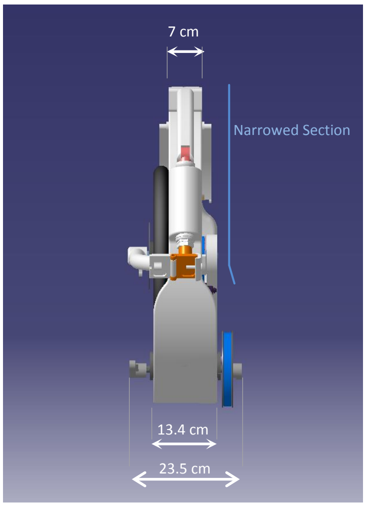

Fig. 11 Front view of 3D foldedversion with dimensions.

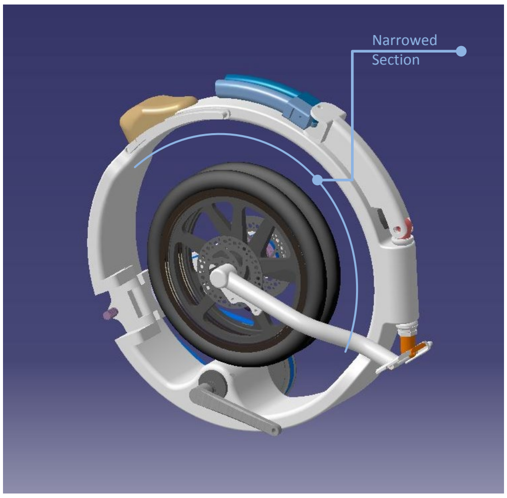

Fig. 12 3D foldedversion (isometric view).

3.5Curved handlebars design

Because the frame is a circularshape,the design of the shape of the handlebars must be curved in accordance with the curve of the frame for the neatness of the fold. Therefore the curvedhandlebars also makes hands to be rested in the correct way as well as illustratedin Fig. 5-6 that angle is 28 degree and 37.6 cm width as show in Fig. 13-14.

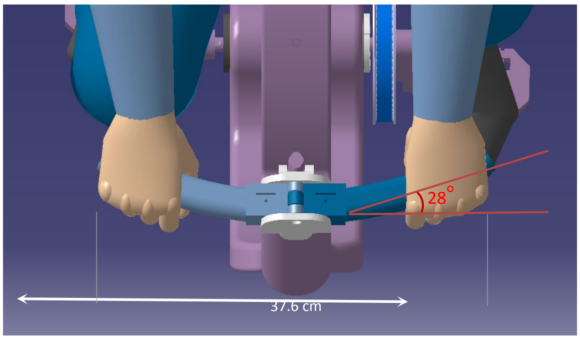

Fig. 13Hand gesture on the handlebars (top view)

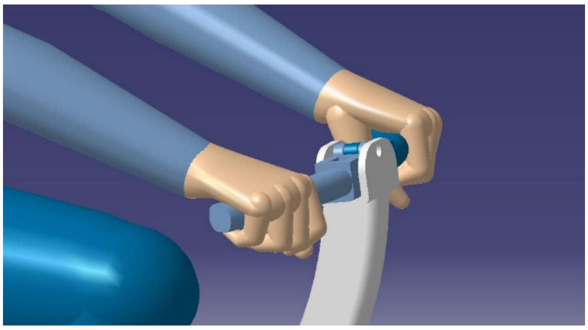

Fig. 14Hand gesture on the handlebars (side view)

4. Theory and calculation

4.1 Forces position and direction

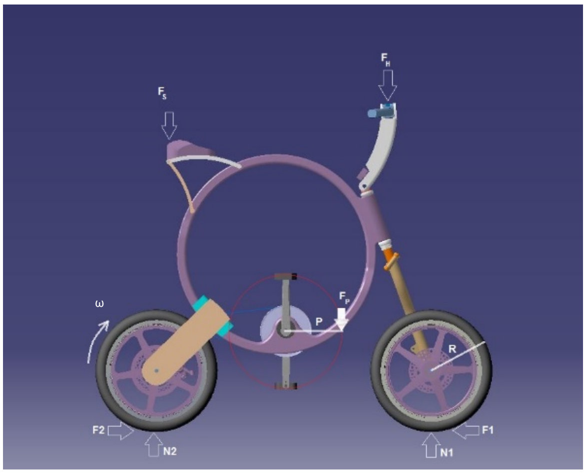

Fig. 15 The model with overall forces

R = radius of the tires
ω = angular velocity of the tires
N_1 = normal force
N_2 = normal force
p = length of pedal arm
F_P = force applied to the pedal arm
F_S = force applied to the saddle
F_H = force applied to the stem
F_1 = reactive push backwards from ground
F_2 = drive force forwards due to torque from pedaling

Fig. 15 shows all forces positions and directions applied on the bicycle then let's set the joint of rear arm and head tube as fix support this method able to deny reaction forces from 2 wheels (N_1 and N_2) as it goes straight through the fixed points. Deny $F_p$and F_H that is slightly low with normal riding positionthat does not affect deformation of the frame.

4.2 Finite element method

4.2.1 Material Property

Material: Aluminum Alloys 6061
Model type: Linear Elastic Isotropic
Default failure criterion: Max von Misses Stress

Table. 2 Property of aluminum alloys 6061

Property	Value	Units
Elastic Modulus	69000	N/mm^2
Poisson's Ratio	0.33	N/A
Mass Density	2700	Kg/m^3
Yield Strength	55.1485	N/mm^2

For apreliminary process, aluminum alloy is the best choice for forming and easy for carry around with its property of a light weight metal. Therefore, the property of metal also give the uniform density which is suitable for testing by FEA method more than other materials such as wood or foam. Italso have a smooth and strong skin that can be used to test the folding system and can also be molded because the skin is smooth and not deformed when in high temperature In the process of making carbon fiber shell as well.

From Table. 2 the computer calculation result mass is 18.53 kg and the volume is 6861.82 cm^3.

4.2.2 Loads and boundary condition

From section 4.1, let's fix the 6 surfaces (blue) and apply 981N of the distributed force onto the 9,000 mm^2seat area (green) as show in Fig. 16.Which the weight/area = 0.109 MPa.

Then the fix area will have an amount of green arrows pointing in and out to represent to direction that is fixed. And on the seat area will have a red arrow pointing down to represent the load direction that is acting on the area as show in Fig. 17.

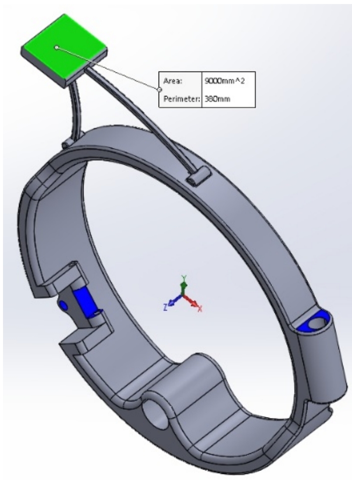

Fig. 16 Selecting loading and support areas

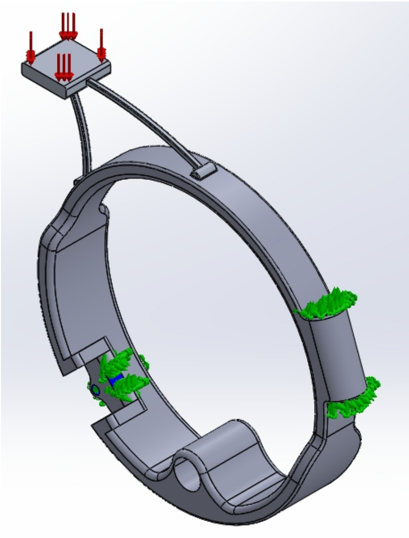

Fig. 17Frame under the condition of loading and support

4.2.3 Define Meshing

'The accuracy that can be obtained from any FEA model is directly related to the finite element mesh that is used. The finite element mesh is used to subdivide the CAD model into smaller domains called *elements'* [6]. For this model, second-order tetrahedral solid element is used. In Fig. 18, calculated total nodes is 270,944 nodes and total elements is 171,376 elements. Maximum element size is 10 mm and the minimum is 2 mm. Which is the good size and number of element that will get a good accuracy along with short CPU time. The result of meshing is shown in Fig. 19.

Mesh Details

Study name	Static1 (-Default-)
Mesh type	Solid Mesh
Mesher Used	Curvature-based mesh
Jacobian points	4 points
Max Element Size	10 mm
Min Element Size	2 mm
Mesh quality	High
Total nodes	270944
Total elements	171376
Maximum Aspect Ratio	35.459
Percentage of elements with Aspect Ratio < 3	97.9
Percentage of elements with Aspect Ratio > 10	0.0379
% of distorted elements (Jacobian)	0
Time to complete mesh(hh:mm:ss)	00:00:36
Computer name	Q190

Fig. 18 Mesh details

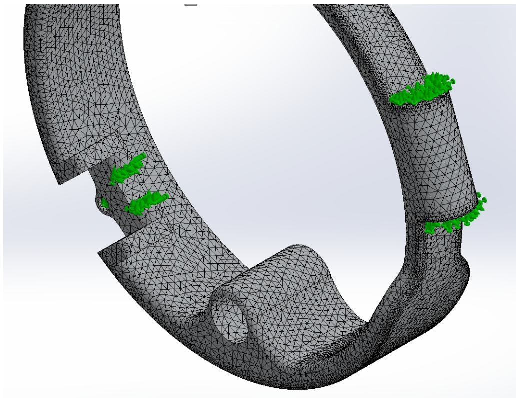

Fig. 19 Meshed O-ring shape frame

4.2.4 Analysis

Compute the test of linear static analysis method under loads and boundary condition in process CPU time about 1 minute.

In term of deformation analysis;the maximum displacement is 0.23 mmas show in Fig. 20that is acceptablebecause it is very small displacement that cannot be virtualization detected and with this displacement value, it cannot deforms the shape.

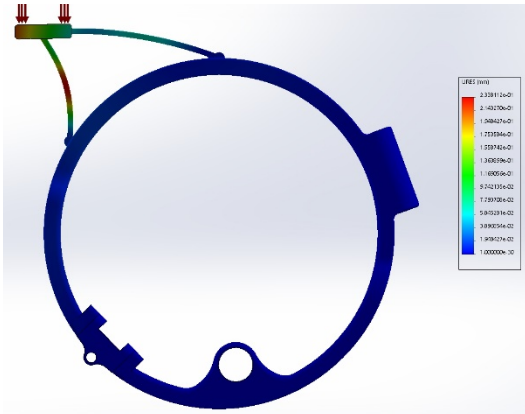

Fig. 20 Overall displacement analysis

In term of stress analysis (Fig. 21); maximum stress occur at seat columnwith value of 124.23 MPa (in Fig. 22) but yield strength of aluminum alloyas defined in Table. 2 is 55 MPa,for this case, the stress at this point exceed yield strength andthis partdefinitely fail. The design needs a stronger joint between the bar and pivot tube. To fix this problem, this point may have anedge fillet or increase size or thickness of the seat column. Overall, the O-ring shape frame able to carry cycling loading very well as the blue color that represent the stress about 1.94×10^{-5}MPawhich is very low, comparing with the yield stress of using material.

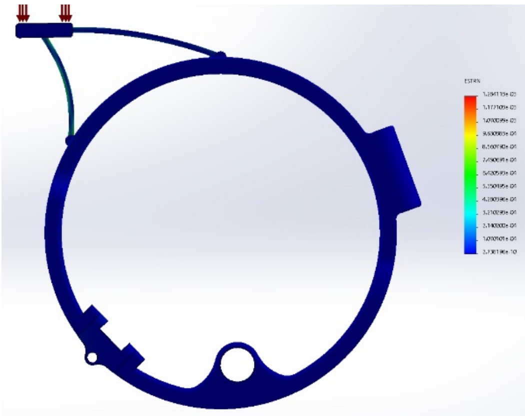

Fig. 21Overall stress analysis

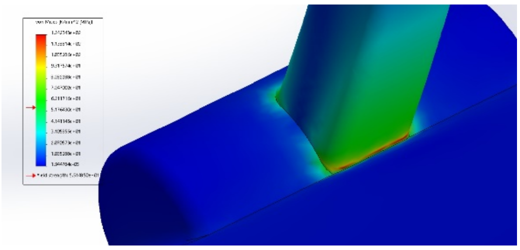

Fig. 22 Maximum Von Misesstress at seat column

5. Conclusion and Discussion

As a result of structural design and development,the bicycle has achieved the goals to have small size and comfortable folding(volume of the unfolded is 123.3 x 102.5 x 15 cm. The dimension, volume of the folded is Ø73.5 × 23.5 cm).The design of the dimensions, positions and functions of the bicycle components can fit properly within the O-ring shape frame in the folded position and cycling position, and also consistent with the ergonomic of cycling position.

The resultsof the preliminary FEA,the maximum displacement is 0.23 mm, which is verysmalland acceptable, and the maximum Von Misesstress at the seat column is 124.23 MPa.This part could fail. Therefore, the seat column needs to be redesigned to be stronger.The rest of the frame is fine with small values of Von Mises stress.

The resultsof this work will be used as a guideline for designing the fiber orientation and stacking sequence of carbon fiber composite material to be used in place of aluminum for reducing weight and improving strength of the O-ring shaped frame.

6. Acknowledgement

Sincere thanks to Associate Professor ThanyaKiatiwat, Ph.D.and Assistant Professor PongthornPhombute, Ph.D.for providing me with all the necessary facilities for the research.Thank to Faculty of Engineering of Kasetsart University for providing me a scholarship.

7. References

[1] “Bicycle,” *Wikipedia, the free encyclopedia*. 20-May-2015.

[2] “Locust bicycle,” *Coroflot*. [Online]. Available: https://www.coroflot.com/josef_cadek/Locust-bicycle. [Accessed: 01-May-2019].

[3] “Roll Up Your Bike | Yanko Design.” [Online]. Available: https://www.yankodesign.com/2012/06/06/roll-up-bike/. [Accessed: 01-May-2019].

[4] “Big#1 Motorsports Blog.” [Online]. Available: http://big1motorsports.blogspot.com/. [Accessed: 02-May-2019].

[5] “ERGONOMICALLY ADJUSTING YOUR BICYCLE - Ergotec.” [Online]. Available: https://www.ergotec.de/en/detail-1/das-fahrrad-ergonomisch-einstellen-63.html. [Accessed: 02-May-2019].

[6] “Finite Element Mesh Refinement Definition and Techniques.” [Online]. Available: https://www.comsol.com/multiphysics/mesh-refinement. [Accessed: 05-May-2019].