

Design, Modelling and Analysis of Tilted Human Powered Vehicle

Vishal Fegade, Gajanan Jadhav, M. Ramachandran

MPSTME, SVKM'S NMIMS, Dhule, Maharashtra, India

gajanan.jadhav@nmims.edu, manickam.ramachandran@nmims.edu

Abstract. Human Powered Vehicle are powered only by muscular-strength. HPV's are moving in road, air, in and under the water. Recumbent bike is one of the type of HPV. Recumbent bike is bicycle with inclined backward seat position and the pedals and bottom bracket are front. In this paper human powered Vehicle (HPV) is designed with a new dimension and analysed. Chassis designed with aerodynamic calculation, its CAD model analysed in Ansys for strength. Fairing is analysed with CFD. So that we can develop new low weight aerodynamic fairing, and four bar tilting mechanism. New design also gives optimum gear ratio with recumbent sitting position. The tricycle has the goals of developing innovative processes and designs for a trike that can be tilted at high speeds for enhanced turning at corners and stable at very low speeds too. The objective is to improve reliability and stability by equipping the vehicle with an aerodynamic fairing such that it can outperform conventional Human Powered Vehicle in all common applications.

Keywords: - HPV; Fairing; CFD.

1. Introduction

The main criterion for the design are 2 wheel drive / 3 wheel drive, Rider position, Frame layout, Material Selection. All critical design decisions were made using weighted average design matrices. The decisions were finalized considering the ease and ride ability of all the riders [1]. The 3-Wheel drive is best when compare with 2-wheel vehicle because 2-wheel vehicle is unstable at low speeds and there is a large loss of speed on turns. Front wheel drive was chosen because front wheel drive was easy to handle. The control of the vehicle was easier than rear wheel drive [2]. The upright position was considered least aerodynamic and would increase the Centre of gravity considerably. Prone position was considered to have the most aerodynamic but was lacking the Centre of gravity. The resultant position favourable was Recumbent. Considering the layout of trike, tadpole or delta was to be observed. Tilt calculations, ease in riding, and other aspects of cycle depend deeply on layout of trike. After finalizing the frame layout we also scored our tilting mechanism to the conventional rigid frame structure. The comparison of table depicted below explains the reason [3]. From a survey we found out that an average Indian person's height is 5 feet and 7 inches so based on that we designed a prototype to find out Best Ergonomic Position, Wheelbase of the Tricycle and Track width of the Tricycle. Tilting is phenomenon used by cyclist to make acute turns with the aid of human weight. Tilting or shifting the weight towards one side at acute turns reduces the external force required for the turn [4]. Tilting helps improving the accuracy of turn at high speeds. Whereas, at low speeds tilt is the evil destroying balance of rider, cycle creating a problem [5]. We have used a tilting mechanism made up of four bar mechanism which will change an outlook of how a tricycle turns at corners. In these mechanism the vehicle will tilt on the turns preventing and loss of speed and remove the case of toppling as centrifugal force is balanced out by the driver's weight [6]. Add on to this is that the vehicle will have full control over the tilting of vehicle and can lock at any instances, like in start by locking it can act a rigid tricycle and be extremely stable at low speeds. As the basic dimensions were fixed we were constrained to the length of the frock along which the tilting of the tricycle will happen. The same trike on cambered roads will allow the rider to be upright and will make certain that the balance of the trike is restored as the rear wheels of the trike are self-adjusting. This would mean that when the trike goes into a bump, the rear wheels align themselves in a way that the impact of the bump is compromised to a great extent. The mechanism is designed in such a way that when one of the wheel gains some height due a stone or a small deformity on the ground, the other wheel instantly loses the amount of height gained. This makes the rider, as well as the trike much more stable than the conventional models of recumbent trikes or bikes. While leaning, the rear wheels automatically align themselves by taking up different heights and hence giving rider the best possible turning radius. The rear wheel crank mechanism not only helps in tilting but also is a key to suspension of the trike.

1. Vehicle Description



Content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](https://creativecommons.org/licenses/by/3.0/). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

Our vehicle, is a delta-shaped tricycle which consists of a controlled tilt mechanism. we considered a wide range of concepts, from a low-riding frame very similar to past designs to an unusual overhead frame from which the rider would have been suspended but finally we eventually selected a frame with low ground clearance in an attempt to correct stability and handling problems [7,8]. From the literature review, we saw several options in terms of frame geometry in the design space defined by the conventional, forward-facing, and recumbent rider position [9]. The frame of our vehicle is made up of Aluminium 7075-T6 with outer diameter (OD) as 38 mm and thickness of 3mm which is a strong material and whose tensile strength is 550 MPa. XLR8 2.0 uses integrated roll bar to protect the rider. The roll bar of the vehicle is made keeping the safety of the rider in mind. It consists of Aluminium 7075-T6 which has a diameter of 30 mm and a thickness of 2 mm. There should be no compromise with the safety of the rider. Also, our vehicle is light-weight and has more strength. Hence, along with the composite material, carbon fibre is added to harden the roll bar and one layer of unidirectional Fibre glass is wrapped on Aluminium 7075-T6. This helps us to ensure full safety of the rider along with the aspects to keep it light-weight and increase the strength and impact resistance of the roll bar. We have use a basic overhead direct steering mechanism because of it easy to install and easily available. Our transmission is based on Front Wheel Drive (FWD) which is a transmission system that provides power to the front wheels of a motor vehicle [10]. In our testing, we compared both Front Wheel Drive (FWD) and Back Wheel Drive (BWD).After the comparison, we found that Front Wheel Drive is a better option. We also saw that in FWD, the bottom bracket is kept fixed and the front tyre rotates. There can be a misalignment in chain. To avoid this misalignment, two idler pulleys are inserted to control the misalignment of the chain. This System is known as FWD twist chain line mechanism. The chain percentage is adjusted in such a way that it is attached by two pulleys. It has 52 teeth sprocket along with 6 speed gear hub. The cock set has a minimum of 14 teeth and a maximum of 28 teeth.

2. CADD Model of Tricycle

Based on the value obtained by the prototype, given below is the chassis design and complete design of the tricycle. Recumbent delta shape tricycle with 1200mm wheel base, 600mm track width, 250mm ground clearance, 45 degree of seat inclination, 18 and 20 inch wheels and Front transmission.After the completion of tricycle the next motive was to convert it from a recumbent tricycle to velomobile i.e.tricycles with full fairing. The purpose of the fairing is to be aerodynamic which will reduce the air drag and provide laminar air flow and almost no turbulence of air on the exit of it from tricycle. Additional purpose is to protect the rider from sunlight, rain etc. The book Human Powered Vehicle compiled a table comparing the aerodynamic data for different vehicle configurations; it shows that a recumbent, faired vehicle can have an extremely low drag coefficient of 0.11 while the standard, prone, two wheel bikes have drag coefficients as high as 1.1.The Fairing team set specific targets prior to the design of the fairing. The focus of each of these goals was to improve vehicle safety, maintain rigidity in the fairing, enhance rider visibility, and make rider access as practical as possible. Due to the high cost of Carbon Fibre, it was rejected and the next best material according to the points table was glass fibre S-Glass. The goals of the test were to determine the optimum crank tube angle and try to get the riders test data at that same angle. The rider went through the test first, then the geometry was adjusted so that the pedals were in position for the rider with relative pedal positions corresponding to the same crank tube angle. The optimum crank tube angle was found through analysis of the rider's tests. The point cloud data was imported into Creo, as with the initial trial, and the vertical gap between the lowest point of the heel marker and where the bottom of the fairing would need to be to clear the speed bump were measured. Next the position of the bottom bracket (centre of rotation of the pedals) for each test configuration was determined. Finally, the lowest allowable crank tube angle was determined.



Fig 1: (b) Rider analysis test

From the above experiment we got to know the extreme points of the rider, while riding i.e the highest knee point, highest pedal point and the path followed by the pedal. Taking the consideration of the measurement from motion capture a side view sketch of the aerodynamic fairing was designed. After the side view sketch of the aerodynamic fairing, From the front view the extreme points were of the RPS, after this we started inserting planes after every 20 cm and on each plane we sketched the fairing. taking the following consideration we took the extreme position of the fairing – hand position of the rider, pedal dimension, RPS dimensions, Sitting position of the rider.

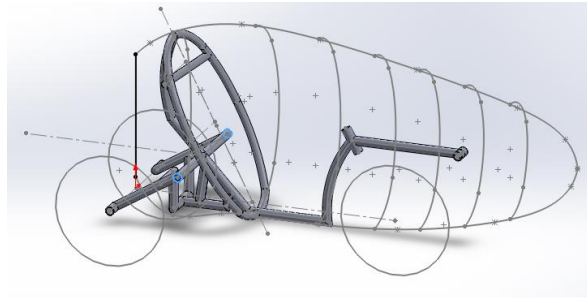


Fig 2: CAD Model of Tricycle

3. Structural Analysis of the chassis (ANSYS):

Various available hollow pipes were considered during the analysis based of the market survey and the best result we got was Outer Diameter- 38 mm AND Thickness – 3 mm. To show that the chassis is able to withstand the weight of the team's heaviest rider in inclusion to some extra cargo the rider must carry during actual use. The team performed FEA of the chassis using ANSYS. A load of 1400N was applied at the position where the rider is supposed to sit. For this analysis, the Maximum (von-Mises) stress was calculated which showed a maximum value of 1.43e8 MPa was found.

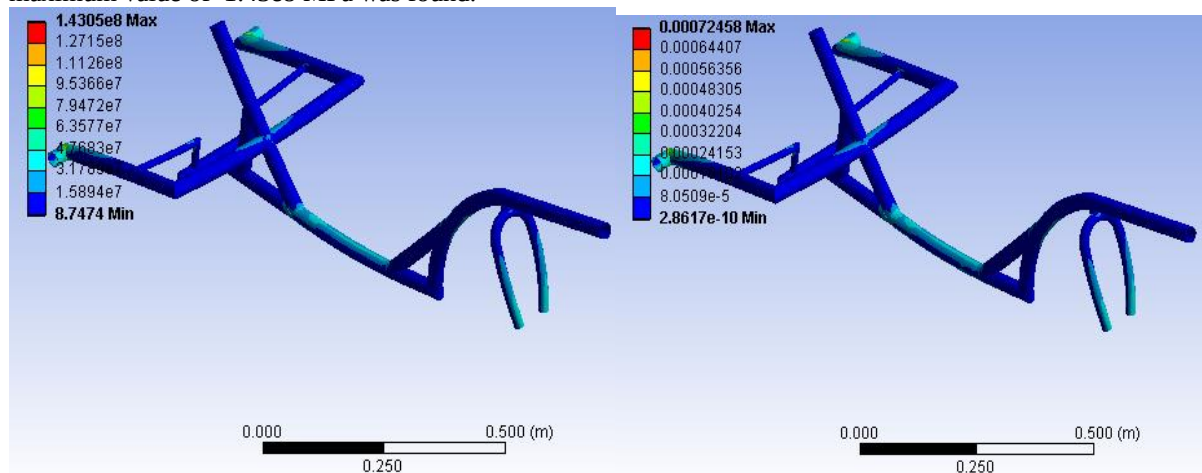


Fig 3: (a) maximum (von-Mises) stress analysis (b)Equivalent elastic strain analysis

To show that the chassis is able to withstand the weight of the team's heaviest rider in inclusion to some extra cargo the rider must carry during actual use. The team performed FEA of the chassis using ANSYS. A load of 1400N was applied at the position where the rider is supposed to sit. For this analysis, the Equivalent elastic strain was calculated which showed a maximum value of 7.24e - 4m/m was found. The factor of safety (FOS) was also calculated showing a minimum value of 8.41. This value was found to be acceptable as we were aiming initially for a FOS of 2.1400 N force is applied in –y axis of direction at the sitting position of driver

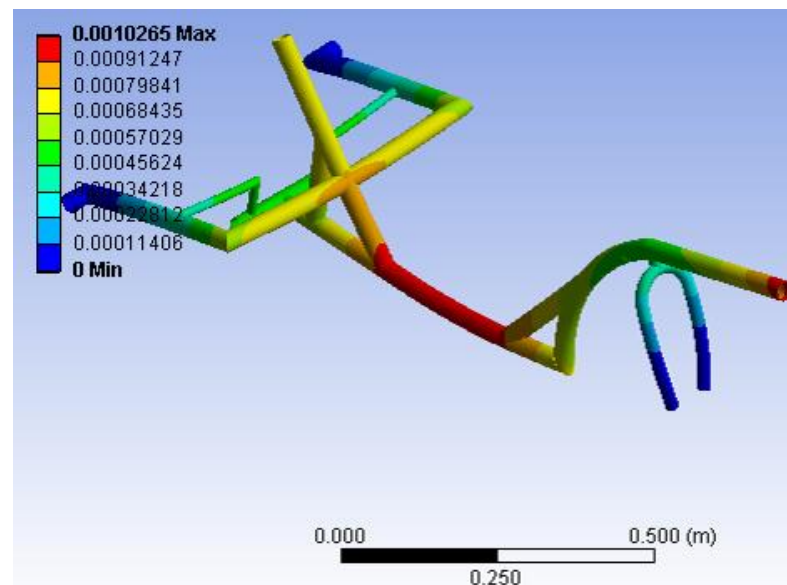


Fig 4: Maximum Deformation analysis

4. RPS Analysis

It is being made up of Aluminium 7075 T6 with outer diameter 30mm and thickness of 2mm and over that layers of Glass fibre E-type is being applied to reinforce its strength. The main objective of the analysis is to ensure the durability of the structure which would ensure the safety of the rider. To ensure that the RPS meet our target and the competition norms, finite element analysis (FEA) was performed by applying load at the top. Since hand calculation proved to be time consuming, FEA was performed using ANSYS 14. For the first condition a top load of 2670 N was applied downwards at an angle of 12° from the vertical. The results were well within our targets, as a maximum deflection of 8.139mm (0.32 inches) was found. For this test, the rear and front forks were assumed to be fixed support and load applied was static load. Figure 5 showing the maximum deflection of 2.1313mm for top load analysis.

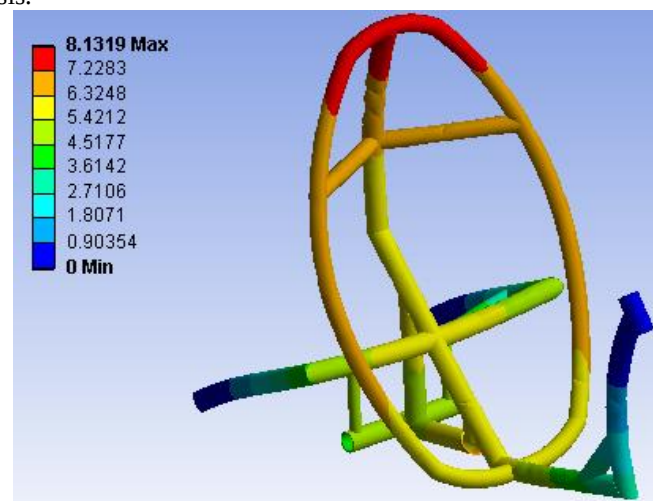


Fig5: Top load analysis

We also found the maximum stress (Von - Mises) induced to be 414.27MPa. The result was acceptable as the value of the maximum stress induced is less than the Ultimate Tensile Strength (UTS) of the material used in the fabrication of the RPS, which is 450 MPa. To further increase the longevity of the RPS, a layer of Glass Fibre will be used to reinforce the RPS

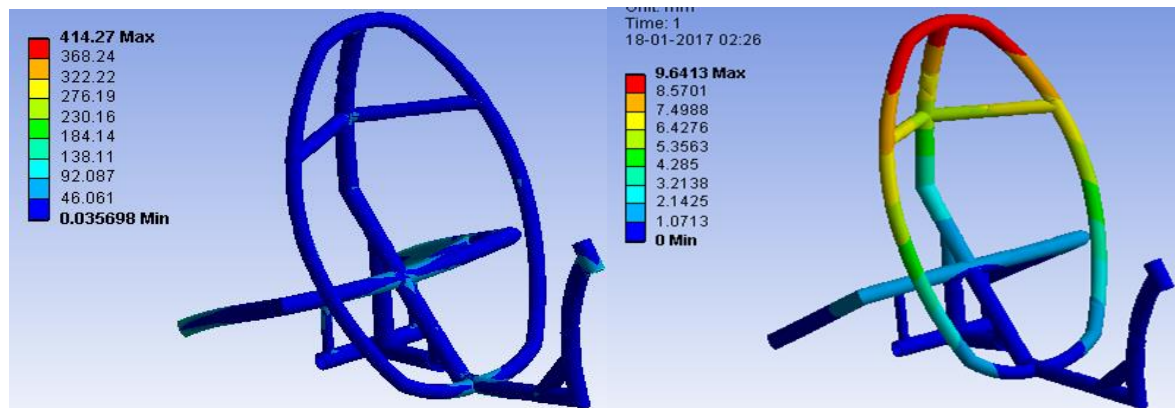


Fig6: (a) Von Mises Analysis (b) Side load Analysis

Side load analysis is used to verify that the RPS will be able to handle the force applied to it, if the HPV is toppled in any accident. For this case, a load of 1330 N was applied acting sideways at shoulder's level's height. FEA was performed using ANSYS. A maximum deflection of 9.64mm was observed. The conditions of fixed supports were same as of top load analysis.

5. Fairing Analysis

The main objective of this device is to decrease the aerodynamic drag created by the HPV as well as provide extra protection to the rider. The most optimum method of analysis was to perform Computational Fluid Dynamics (CFD) on a CAD model of the device using ANSYS Fluent. The CFD would provide us with a value of Drag Coefficient which would be used to calculate drag force. The coefficient of drag (C_D) computed from CFD was 0.11 and drag force of 7.42N.

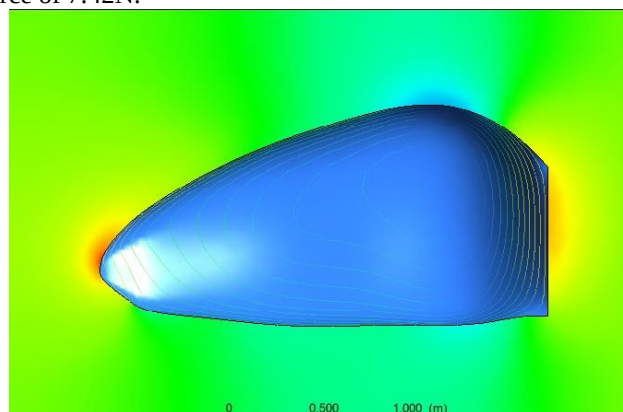


Fig 7: CFD Analysis on CAD Model

6. Conclusion

The frame built is light-weight and is designed in such a way that the load distribution of the frame is even throughout. Also, the design of the frame is such that maximum strength and stability can be achieved by the vehicle. The best coefficient of drag (C_D) computed from CFD was 0.11 and drag force of 7.42N. In future, we can improve vehicles torsional stiffness by modifying the geometry of the fairing and the modular of the fairing can be improved by improving the design. Seat can be improved to prevent the slide down over the long time use.

References

- [1]. Alam, Firoz, Harun Chowdhury, Erika Guillaume, Jie Yang, and Gary Zimmer, *Procedia Engineering* 60 (2013): 473-478.
- [2]. Gross, Albert C., Chester R. Kyle, and Douglas J. Malewicki, *Scientific American* 249, no. 6 (1983): 142-152.
- [3]. Kyle, Chester R., and Vincent J. Caiozzo, *International Journal of Sport Biomechanics* 2, no. 1 (1986): 6-19.

- [4]. Kyle, C. R., and M. D. Weaver, Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy 218, no. 3 (2004): 141-154.
- [5]. White, A. P, Journal of sports sciences 12, no. 5 (1994): 419-421.
- [6]. Cox, Peter, Built Environment 34, no. 2 (2008): 140-160.
- [7]. Too, Danny, Sports medicine 10, no. 5 (1990): 286-302.
- [8]. Osse, James, In OCEANS'89. Proceedings, vol. 6, pp. 7-11. IEEE, 1989.
- [9]. Alam, Firoz, Pedro Silva, and Gary Zimmer, Procedia Engineering 34 (2012): 9-14.
- [10]. Suryanarayanan, Shashikanth, Masayoshi Tomizuka, and Matt Weaver, 2002. Proceedings of the 2002, vol. 2, pp. 845-850. IEEE, 2002.