DESIGN SELECTION AND ANALYSIS OF THE CHASSIS / FRAME OF A HUMAN POWERED VEHICLE

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Abstract- ***This work was done with the vision of building awareness regarding human powered vehicles in masses. This work primarily focuses on the chassis / frame section of a human powered vehicle. The chapter-wise breakdown of the report starts with introducing the human powered vehicle and objectives of the design, reviews the existing literature, presents the design selection of the vehicle, briefs about the basic stages of design yet so important, analysis of the design which involves checking the strength of the chassis / frame material by loading at the desired points and the problems occurred while testing. It also discusses the solutions and rectifications of the problems or errors in design. This work will help to create an awareness about the various other alternatives available over the existing models of transportation that is not only feasible but also efficient in all aspects. Highlighting one of the main problems of the world, this work drive towards a thought that if advancements are driven towards this subject of interest, there could be many extreme problems solved with ease and less effort.***

Keywords-Human Powered Vehicle, chassis, frame, ergonomics, roll-over protection system, recumbent.

1. INTRODUCTION

Wheel has been the greatest invention of human race. Since ancient civilizations, the wheel has been primarily used for trade and transportation. Due to increase in trade and transportation, wheel has evolved in various forms of bullock carts to autorickshaws to automobiles to airplanes, etc. Today, automobile has become an integral part of human life and of trade and transportation as well. Trade is also a very important component of Globalization.

But, due to this increase in transportation and trade which ultimately leads to increased use of light and heavy automobiles, global pollution level is observing record high levels owing to emission of greenhouse gases, ozone depletion, increased temperature, etc. A concern of fossil fuels getting exhausted is also to be considered. In such a case, there is a need to find a smart alternative which is a combination of being eco-friendly, fast and most importantly being very safe. A human powered vehicle is the solution of all these needs. As the name suggests, a human powered vehicle does not require consumption of any kind of fuel, be it renewable or non-renewable.

Figure 1 A Human Powered Vehicle

Human Powered Vehicle is a manually driven vehicle verysimilarto a traditional bicycle with certain variations in design to cause the driver less effort in driving the vehicle. The vehicle is designed to be a light weight, efficient, fast and reliable by the means of testing and analyzing the design while being in the process of continuously improving it. Being safe on the other hand, it also eliminates the risk of fatal accidents which is also a drawback of conventional vehicles. A human powered vehicle is the future of sustainable, smart means of transportation.

The entire design process and fabrication were carried out in multiple stages. An entire process flow is shown in Fig.2.

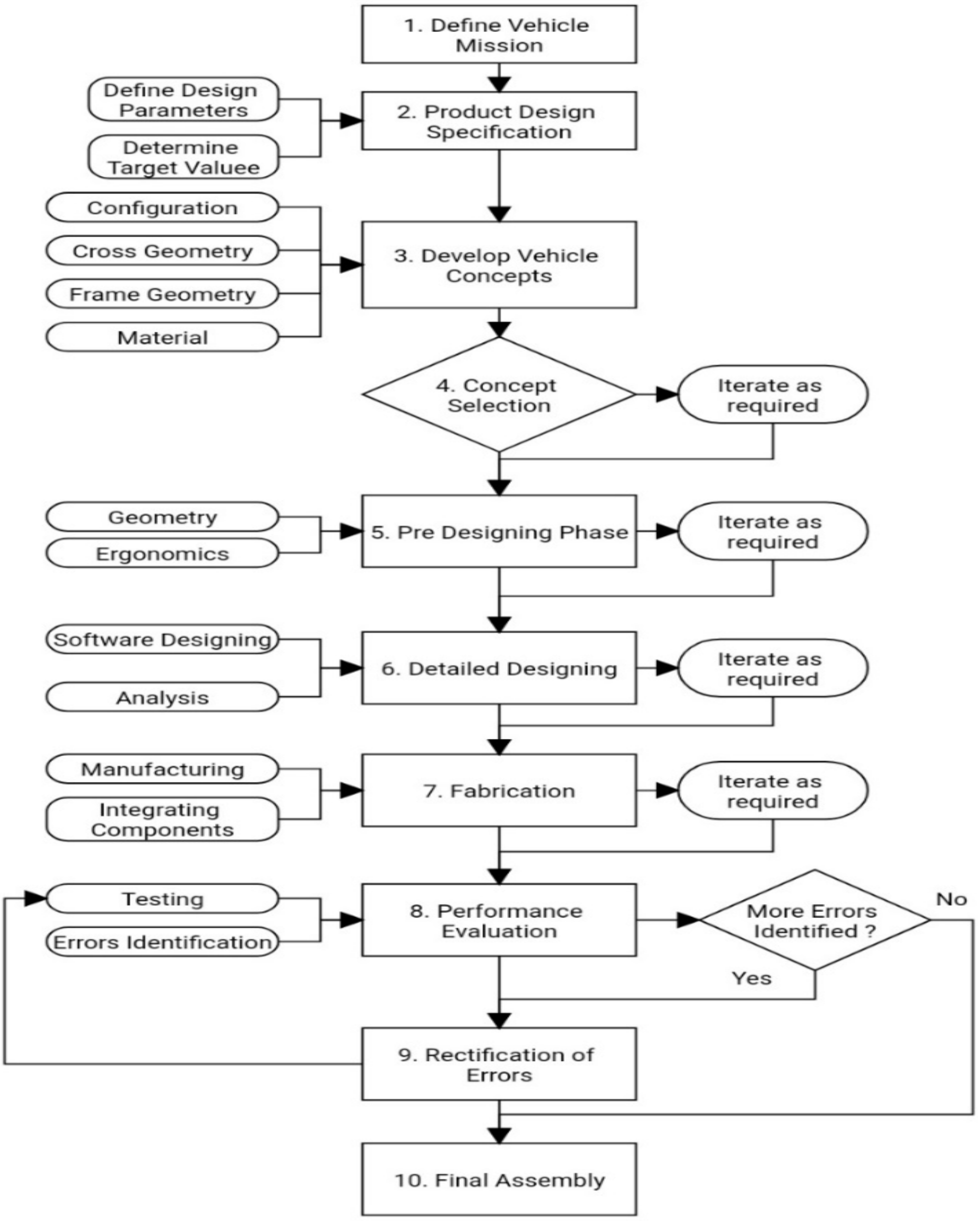

Figure 2 Process Flow Chart

1.1 OBJECTIVES

Certain Objectives of designing a human powered vehicle are listed below:

1. To create a smart alternative for the existing means of transportation.
2. To create a vehicle which provides uncompromising safety.
3. To create a vehicle which is eco-friendly.
4. To create a vehicle with increased durability and speed.
5. To create a vehicle that promotes fitness.

2. LITERATURE REVIEW

Human Powered Vehicles have been developed in many significant ways and are in use today in many countries. There had been many significant researches on this topic of interest. It is very important to understand about the similarities and dissimilarities between human body and the engine of an automobile. Energy is taken in through fuel (food and drink, in the case of humans). “Useful” energy is put out in the form of torque on a rotating crankshaft (in the case of cars) or in a variety of muscular movements (in the case of humans); and “waste” energy is dissipated as heat [1]. Except the use of human power on land vehicles, it can also be used for transport in many different capacities, including flying and boating [2]. A point of interest with respect to this project is its discussion of human power output capability. The difference between the upright bicycle and these recumbent bicycles and tricycles is that with bicycles, only the legs can be exercised, but for a recumbent position, the operator uses his whole body to create a motion. This is due-to-the fact that the operator is lying horizontally or almost horizontally on the sliding bicycle seat and pushing the pedals with his legs, simultaneously sliding his body on the frame of the bicycle by pushing with his hands on the handlebars [4]. Innovations and creativity have even led to the development of a collapsible vehicle which you can carry along with wherever you go [5]. Latest versions of the human powered vehicles include positioning the rider inside a fully faired configuration in the attempts of increasing the speed to a greater extent, the chassis of the vehicle drafted with a minimal ground clearance in order to increase the control of the vehicle [6].

A thorough study of the chassis section was done by the team members referring to different printed and electronic media available through books, journals, articles, videos, etc. Being working on the most important section of the vehicle, it was necessary to come up with a concept that is rider efficient observing safety as the primary vision of concern. The concept and configuration of the vehicle was selected based on the study followed by the designing of vehicle on appropriate CAD software and analysis of the same.

3. PRE-DESIGNING PHASE

3.1 CONCEPT DEVELOPMENT AND SELECTON METHOD

In this phase, it was needed to finalize two important parameters of the design;

(i)Vehicle Configuration

(ii)Material Selection

For both these parameters; analysis of all the alternatives, comparison on the basis of suitable criterion was carried out and ultimately a three-wheeled tadpole configuration of the vehicle and AISI 4130 as the chassis material was finalized.

Chemical Composition of AISI 4130 –

Table 1 Elements and their composition in AISI 4130

ELEMENT	COMPOSITION
Carbon	0.28- 0.33
Chromium	1.8 – 1 .
Manganese	1.7 – 0 .
Molybdenum	1.15 – 0 . 2
Phosphorus	1.35 M a
Silicon	0.15 – 0.35
Sulphur	0.04 max

(i)Vehicle Configuration:

There were many alternatives for vehicle configuration [3] such as – Tadpole, Delta, Streamliner and Quad. To compare them we considered safety, stability, rider's comfort, weight, cost, aerodynamics as the selection criteria. Keeping safety and stability as the primary concern Tadpole structure proved out to be heavily weighted.

(ii) Material Selection:

Having innumerable options to choose from [3] we narrowed down our final options to Al 6063, AISI 4130 and carbon fiber on-the-basis of availability of these materials in the city. The selection criteria involved its machinability, weight density, cost, strength to weight ratio and availability. Ultimately, AISI 4130 proved out to be heavily weighted.

The decision-making process was implemented using Pugh's selection method of involving decision matrices.

3.2 ERGONOMICS

The objective of performing this test before designing phase was to help in designing an ergonomically stable and rider friendly vehicle. The following data were determined after the test was performed.

(i)Most comfortable backrest-angle.

(ii) Most comfortable steering handle position for varying heights ofriders.

(iii) Optimum distance of pedals from the hip for knee or thigh not to obstruct the viewing angle.

A setup was built that would determine the requirements. This setup was built in a way that it would provide the results with minimum errors. Hence, accordingly the test was conducted, and the required values were obtained. For ex.: The backrest was adjusted at 1300, 1350, 1400 of which 1350 was most comfortable for the rider. This seating position is often termed as semi-recumbent.

4. DESIGN AND MODELLING PHASE

'Chassis' is the skeleton of the vehicle. Chassis is often called as frame of the vehicle. All the external variable loads act directly or get transferred on the chassis. A well-designed and fabricated frame is strong enough to withstand all normal service loads, stiff enough to ensure good handling response and efficient power transfer, yet light and comfortable for the rider. These are stringent requirements demanding much attention during design.

The frame design was started with known loads and reactions [3]. This generally meant that vehicle gross geometry and rider position was determined prior to designing the frame. Keeping all these into consideration, the vehicle frame was designed in two parts – the front chassis and the rear chassis which could be detached in the first iteration.

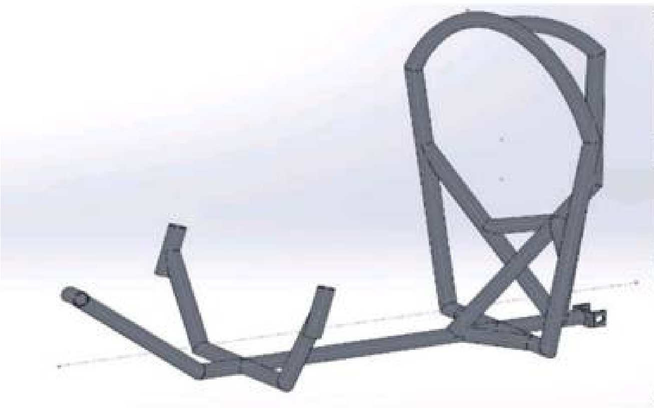

Figure 3 Front Chassis

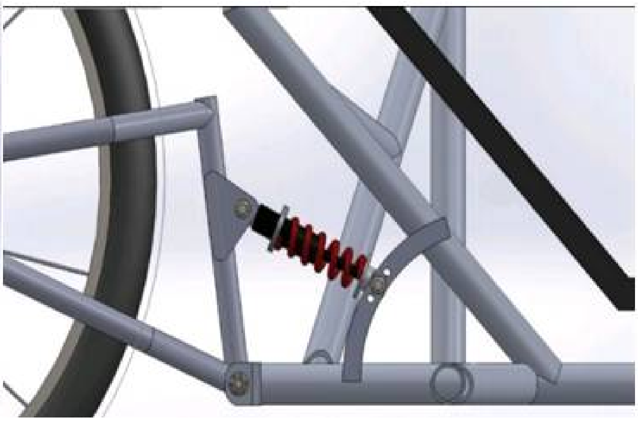

Figure 4 Rear Chassis

One of the most important components of the chassis design was the Roll-over Protection System, abbreviated as 'RPS'. A roll-over protection system is a system of members mounted on the chassis that helps in protecting the rider in case of impacts or accidents. The RPS had been designed in such a way that the rider's body will be entirely contained inside the vehicle in case of front or side rollover. Considering extreme conditions of roll over, the probable impact points on the rider's body were determined and it came out to be majorly affecting the rider's head and shoulder to hands section. Rider being tightly harnessed to the chassis (i.e. the harnesses were mounted on the chassis members), he/she were completely safe as far as injury to any other body parts were concerned. Hence, a roll-over protection system was designed to protect the head in case of front roll-over and shoulder to hands section in case of side roll-over. Following figure shows the RPS design:

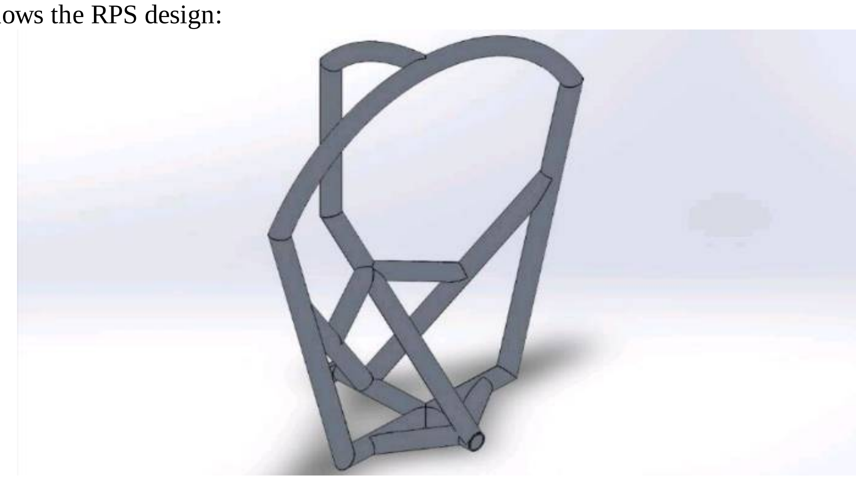

Figure 5 Roll-Over Protection System

After the entire designing phase was over i.e. when CAD of the entire vehicle was ready along with the chassis and other parts incorporated, it was now time to analyze the vehicle of its strength and other factors involved while riding the vehicle. A draft of the vehicle is shown in the vehicle below (1st iteration):

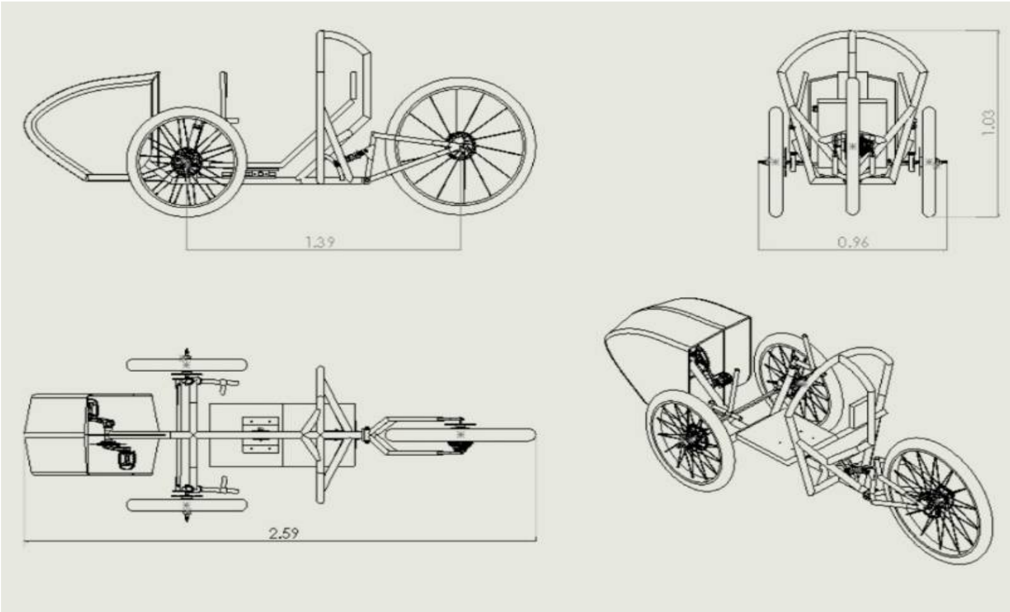

Figure 6 Draft of the vehicle

5. ANALYSIS PHASE

Various modes of failure were identified of various members [7,8,9] and the analysis by applying maximum loads was carried out mainly on RPS specially to conclude if it is safe in case of roll over. The analysis of main chassis rod was also done to determine if it is strong enough to carry the weight of the rider. Following images show the results from the analysis software:

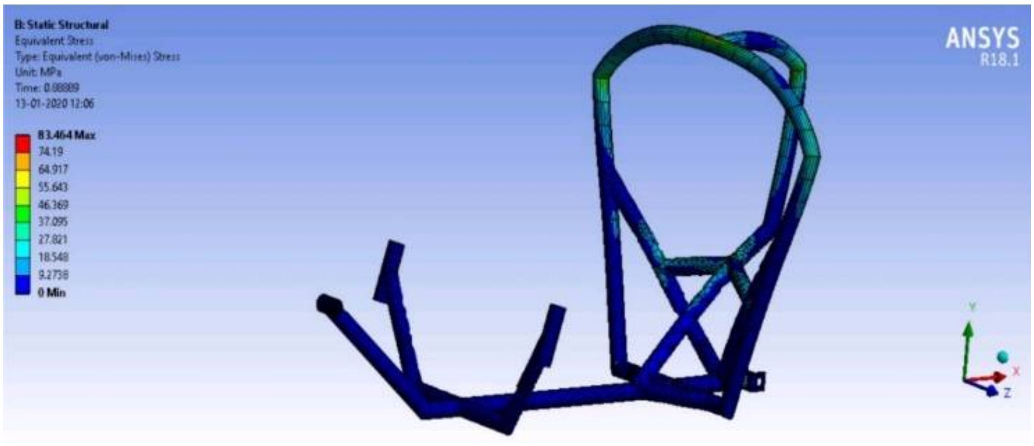

Figure 7 Analysis of RPS

Appropriate magnitudes of load were applied on various points, and the analysis inferred a maximum Von-Mises stress of 80 – 170 MPa.

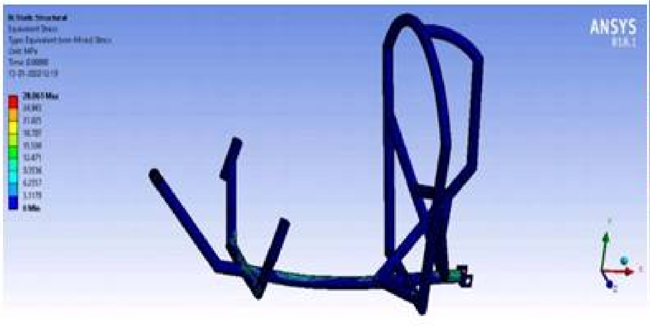

Figure 8(a) Frame Stress Analysis

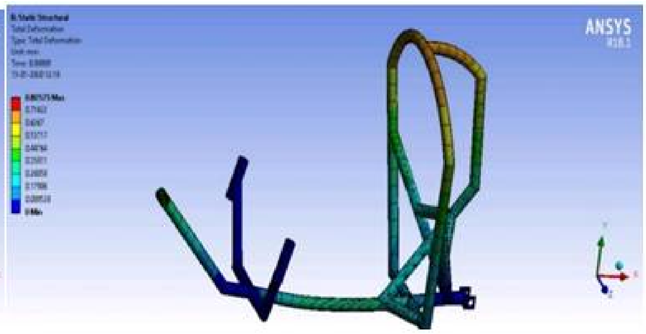

Figure 8(b) Frame Deformation Analysis

In case of main rod analysis, a load 50% more than the rider's weight was applied, and the maximum Von-Mises stress was just 28 MPa with a deflection of a minimal value of 0.805mm.

5.1 MATERIAL DATA

The material data that was fed in the software or the material specifications used are:

Table 2 Physical Properties of AISI 4130

PROPERTIES	VALUES
Density	7.85 g/cc
Tensile Strength, Ultimate	670 MPa
Tensile Strength, Yield	435 MPa
Modulus of Elasticity	205 GPa
Bulk Modulus	140 GPa
Poisson's Ratio	0.29

6. RESULTS AND RECTIFICATIONS

6.1 PROBLEMS / ERRORS AFTER TESTING

1) In impact load testing, the frame was made to fall freely from approximately 3 metres, which resulted in a deformation of main rod due to vibrations in the frame. This deformation came out to be around 4 cm.
2) In roll over testing with the rider in the vehicle, the RPS got tilted sideways.
3) The front members of the frame that ran between the front tyres also got deformed by a significant amount.
4) Both the front wheel axles bent vigorously multiple times even after switching to a stainless-steel axle.

6.2 RECTIFICATIONS MADE IN THE DESIGN AND ITS OUTCOMES

These rectifications of the above - mentioned problems led to the second iteration of the vehicle. In this second iteration, the major goal was to increase the strength of the vehicle at the same time not increasing the weight. Following are the rectifications made in the second iteration:

1)The strength of the main rod was increased by welding two more rods of the same size running parallel to it on either of its sides. It not only helped in getting the load distributed but it also resolved the problem of RPS tilting since it was just supported on a single main rod in the first iteration. It also helped the front member to get balanced on three supports. In this way, a single rectification resolved three major deformation problems.

2) Two forks were used to govern the two front tyres which helped in distributing the weight thus causing the axle not to bend.

3)Another cause identified of axle bending was unequal weight distribution due to a long wheelbase (i.e. the distance between the centers of front and rear wheels). The weight was made relatively more distributed by eliminating the rear chassis which helped in decreasing the wheelbase, hence making chassis a single frame.

4)Elimination of rear chassis caused the removal of suspension as well whose use was not identified significant in the vehicle, thus compensating the increase in weight due to installation of extra two main rods.

5)Some members of the RPS were also substituted by fewer members which helped in reducing weight and did not show any compensation in strength.

As a result of these rectifications, the chassis was found to be strong enough to sustain the normal service loads. Image below shows the final finished product safe enough to feel the roads.

Figure 9 Fully assembled vehicle

7. CONCLUSIONS

1) This work has been carried out to help engineers get a brief idea of the frame / chassis of a human powered vehicle and encouraging them to come up with new ideas enhancing it to a much greater extent.

2) It is very important and necessary to plan the timeline in advance in order to attain a smooth process and that knowledge of planning the stages is only possible if one has a perfect understanding of the subject.

3) One cannot attain the exact same product as designed, there is always variations in the manufactured product and that one needs to plan and consider before-hand.

4) Finite Element Analysis (FEA) results can be relied entirely if performed with extreme brilliance but not otherwise. Suggestion would be not to rely entirely on FEA results.

5) Basic testing of the vehicle was performed to examine any further deformations occurring in the frame. Multiple rides were executed by different riders and fortunately none of the riders and the vehicle were harmed during the process.

6) Attempt would be to further decrease the weight of the vehicle, try different configurations and make the vehicle more viable. Also, considering a fully faired configuration to enhance the aerodynamic properties of the vehicle would be a good point of study. Also, a collapsible vehicle is an option to ponder upon.

7) It is obvious that the RPS members increase the overall weight of the vehicle, hence an RPS should be designed such that it does not increase much weight of the vehicle and at the same time safe enough to contain the rider.

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