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Analysis of a Human Powered Vehicle

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Abstract- The aim of this paper is to analyze a Human Powered Vehicle (HPV) that is lightweight, efficient, and can be effectively driven for long range. The paper's scope included all aspects of vehicle design. A broad spectrum of analysis was implemented to ensure that the desired vehicle performance is met, while simultaneously satisfying all other safety requirements. In-order to increase the human powered vehicle performance, a fully faired vehicle was opted. The design configuration of HPV is a semi recumbent bicycle that enhances the range of cycling and increases the speed by the aerodynamically designed fairing. A three-point safety harness, 200 degree field of vision and a rollover protection system (RPS) was used to ensure rider safety in all scenarios. Through the use of sound engineering principles, the designed HPV has a coefficient of drag of 0.20 and achieved a top speed of 60 kmph.

Index Terms-Human power vehicle, ansys, HPV.

1. INTRODUCTION

HPV means "Human Powered Vehicle". This term includes all vehicles that are powered only by muscular-strength. The large area of HPV can be divided into many categories. The largest is the bicycle. But you can find HPV's in the air, in and under the water and also on the rail. Some HPV's are built for competition to get faster and faster, but others are for daily use, like the rickshaw in India. A real HPV can be powered by an electric engine, but the energy must come from a human powered generator. Electric bicycles with batteries onboard do not include to HPV's.

There has been constant evolution in HPV industry. The vehicles have evolved from the primitive type to the modern recumbent and velomobiles.

1.1 Objective

Our objective is to design and fabricate a vehicle that -

i) Increases the range of cycling
ii) Has got an aerodynamic advantage
iii) Ensures the safety of rider
iv) Economical to fabricate.

1.2 Rollover Protection System

All vehicles must include a rollover protection system (RPS) that protects all drivers in the vehicle. In the event of an accident. Functionally, the RPS must:

- Absorb sufficient energy in a severe accident to minimize risk of injury
- Prevent significant body contact with the ground in the event of a fall (vehicle resting on its side) or rollover (vehicle inverted)
- Provide adequate abrasion resistance to protect against sliding across the ground. This is particularly important around the rider's arms and legs. Adequate guarding must be included.
- RPS Load Cases: The RPS system shall be evaluated based on two specific load cases – a top load representing an accident involving an inverted vehicle and a side load representing a vehicle fallen on its side. In all cases the applied load shall be reacted by constraints at the seatbelt attachment points; simulating the reaction force exerted by the rider in a crash.

(a) Top Load: A load of 2670 N per driver/stoker shall be applied to the top of the roll bar(s), directed downward and aft (towards the rear of the vehicle) at an angle of 12° from the vertical, and the reactant force must be applied to the seat belt, seat, or roll bar attachment point and not the bottom of the roll bar (unless the bottom is the attachment point). Note that there may be one roll bar for the driver and another roll bar for the stoker which will result in each RPS having an applied load of 2670 N,the driver and stoker can both be protected by a single roll bar which will result in the RPS having an applied load of 5340 N. The roll bar is acceptable if 1) there is no indication of permanent deformation, fracture, or delamination on either the roll bar or the vehicle frame, 2) the maximum elastic deformation is less than 5.1 cm and shall not deform such that contact with the driver's helmet, head or body will occur.

(b) Side Load: A load of 1330 N per driver/stoker shall be applied horizontally to the side of the roll bar at shoulder height, and the reactant force must be applied to the seat belt, seat, or roll bar attachment point and not the other side of the roll bar. Note that there may be one roll bar for the driver and another roll bar for the stoker which will result in each RPS having an applied load of 1330 N, or the driver and stoker can both be protected by a single roll bar which will result in the RPS having an applied load of 2670N.

The roll bar is acceptable if:

- There is no indication of permanent deformation, fracture or delamination on either the roll bar or the vehicle frame.
- The maximum elastic deformation is less than 3.8 cm and shall not deform such that contact with driver's helmet, head occurs.
- RPS Attachment: The RPS must be structurally attached and braced to the vehicle frame or fairing and, with the vehicle in the upright position, must extend above the helmeted head(s) of the driver(s) such that no part of any driver will touch the ground in a rollover or fall over condition. The RPS may be incorporated into the fairing, providing that that part of the fairing is used in all events. Teams must demonstrate that the RPS meets both functional requirements and loading requirements.

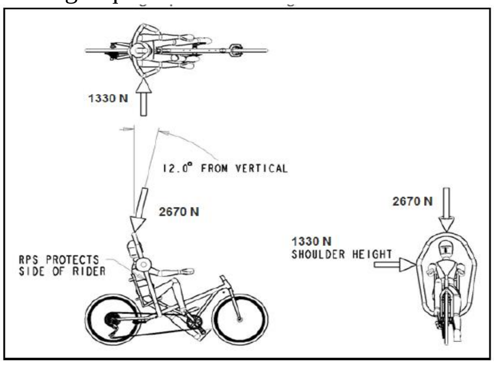

Figure 1: Example of Proper RPS Design and Side and Top Load Case Applications (Note: Loads shown should not be applied concurrently in analysis and/or testing)

1.3 Performance safety requirements

Each vehicle must demonstrate that it can come to a stop from a speed of 25 km/hr in a distance of 6.0 m, can turn within an 8.0 m radius, and demonstrate stability by traveling for 30 m in a straight line at a speed of 5 to 8 km/hr (fast paced walking speed).

1.4 Cadence

It is evident that cycling performance would appear to be dictated largely by the ability of the cyclist to produce high power outputs at minimal metabolic costs. As pedal rate (i.e. cadence) can influence both the ability to produce power, as well as rate of energy consumption, cadence selection could have a significant impact on cycling performance. While information concerning pedal rate selection during cycling exists, a comprehensive review of the present literature is not currently available. As such, the cadence that results in the best possible performance outcome during the vast array of cycling events and conditions remains unclear.

An elucidate knowledge about cadence abets the selection of efficient drivetrain configuration. To get a better understanding in this aspect we have taken aid from the research papers: Optimal cadence selection during cycling Dr Chris R Abbiss, Dr Jeremiah J Peiffer, , Paul B Laursen, Preferred pedalling cadence in professional cycling Alejandro luci ´a, jesu ´ s hoyos, and Jose ´ . Chicharro

Factors affecting the cadence

(i) Muscular Factors

Pedal Forces

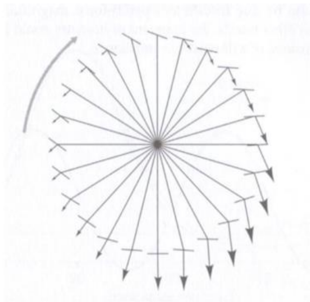

Figure 2: Showing pedaling force acting on the pedal throughout a complete rotation

The above diagram is demonstrating the direction and magnitude of pedal forces throughout a typical clockwise pedal cycle and note counterproductive (negative) pedal forces during the upward phase of the pedal cycle.

(ii) Non muscular factors

The non-muscular components refer to other factors that may influence pedal or crank forces, such as gravity or inertia.

1.5 Aerodynamics

Though we covered most of our bases during preliminary research and design planning, for exploiting the aerodynamic advantage we had to refer 'Race Car Aerodynamics by Joseph Catz' to get familiar with the fundamentals of aerodynamics and for design process various air foils have been studied.

1.6 Fairing

Aerodynamics play a major role when cycle achieves speeds over 30 km/hr. Drag becomes dominant when you cross 30 and most of the cyclist's effort goes into overcoming the drag which results in restricting speed of the cycle .Hence we decided to go with a fully faired cycle and making subtle changes to fairing so as to contain practical difficulties like vision, clearances etc.

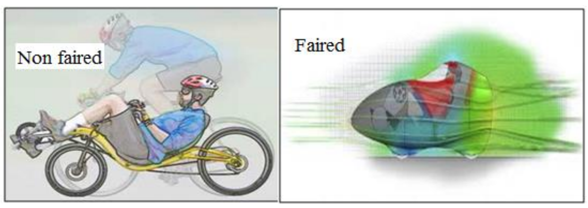

Figure 3: Comparison between non-faired an faired HPV

2. DESIGN

Designing of an HPV began by visiting- 'The Bike Affairs' – a bike shop which gives professional support, and several bicycle outlets. Interacting with the professionals gave us a better insight on various component selections and cadence which is the determining factor for a long range cycling. Moreover, this has also elucidated us about the latest high grade bicycle components that improve the drive efficiency and the quality of ride. After extensive literature survey, with right guidance from professors and support from field experts we were able to finalize our design that met our objectives. However, we faced quite a challenge to select the fairing material that is easy to fabricate. So we visited 'Yen Plast Industries' to study various materials and fabrication patterns.

2.1 Design Specifications

Performance

Design Goals	Specifications/Methodology
Vehicle should stop within 6m while travelling at a speed of 25 kmph	Front and rear rim braking system
	Direct steering with steering angle of 10.53 deg.
Minimum of 8m radius of turning	Stability maintained at 5 kmph by using effecting steering system and drivetrain.
Should travel for 30m at a speed of 5 – 8 kmph	
	Top speed of 55 kmph - Drivetrain analysis.
Top speed >50 kmph	Full fairing; Cd – 0.2
Exploit aerodynamic advantage	

Safety

Design Goals	Specifications/Methodology
To include RPS to protect the rider during accident.	Roll bar has been incorporated
RPS : It should withstand top load of 2670N and side load of 1330N with maximum deformation of 5.1cm and 3.8cm respectively	Seat belt Horn Headlight Taillight Rear view mirrors Side reflectors
Should include necessary safety harnesses and accessories to ensure safety of rider and bystanders	
aerodynamic advantage	

2.2 Material Selection

Steel being indigenous material in our locality compared to other materials like aluminum, carbon fiber that could be used for manufacturing a human powered vehicle. The ease with which a HPV can be manufactured using steel and its higher resilience- this property is as there are no suspensions in our HPV; compared to aluminum were the primary reasons we opted steel for manufacturing the main frame of our HPV. IS 4923 and IS 3074 was used to fabricate the frame member, this was selected based on the results of design analyses conducted.

2.3 Aerodynamic Devices

Aerodynamics play a major role when cycle achieves speeds over 30 kmph. Drag becomes dominant when you cross 30kmph and most of the cyclist's effort goes into overcoming the drag which results in restricting speed of the cycle .Hence our team decided to go with a fully faired cycle and making subtle changes to fairing so as to contain practical difficulties like vision, clearances etc. We chose FRP as the fairing material based on the decision matrix shown below.

Table 1: Decision matrix of fairing materials

Parameter	Weightage	FRP	Carbon Fiber
Cost	0.391	5	2
Mold	0.252	4	2
Strength/Weight	0.173	2	5
Laying	0.073	4	3
Rigidity	0.111	3	4
Total		3.94	2.81

2.4 Braking System

Our vehicle is designed to attain high speeds over 50 kmph, being a high performance vehicle; it is necessary to have an efficient braking system. Various parameters such as cost, manufacturability, brake power, weight and other complexities (effect on wheel movement) were considered while selecting the components of braking system.

Table 2: Decision matrix for type of brakes

Parameter	Weightage	Rim	Disc	Drum
Brake Power	0.335	4	5	4
Manufacturability	0.172	5	4	2
Weight	0.280	5	3	2
Other complexities	0.094	5	3	2
Cost	0.119	4	3	2
Total		4.55	4.12	2.67

3. SOLIDWORKS MODEL OF HPVC

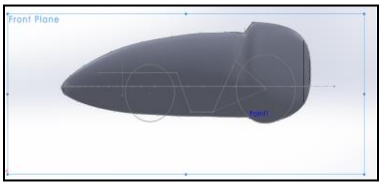

Figure 4: Side view of HPV

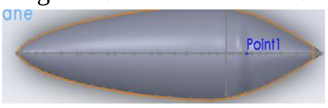

Figure 5: Top view of HPV

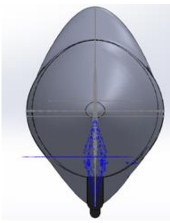
Figure 6: Front view of HPV

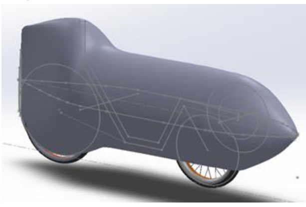
Figure 7: Isometric view of HPV

4. RESULTS AND DISCUSSION

The RPS is provided to protect the rider from impact with the ground in case of a vehicle roll over. In the analysis the seat belt mounting points are fixed and the load 2670N (as stated the ASME HPVC 2018 rules) is applied at an angle of 12degrees inclined towards the rear of the vehicle. The vonmises stress induced and maximum elastic deformation was calculated.

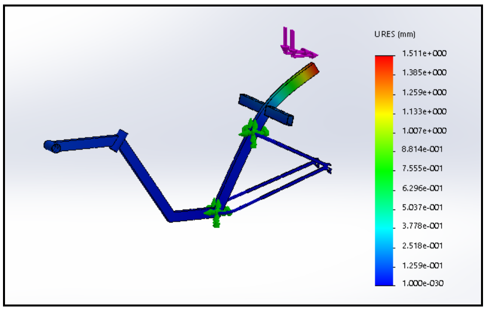

Figure 8: Maximum elastic deformation of 1.51mm was obtained for the top load analysis on the RPS

Table 3: Result for RPS analysis

Case	Max. elastic deformation (mm)	Max. Vonmises stress (MPa)	Factor of Safety
Top load	1.51	120	1.359
Side load	4.005	55.7	3.17

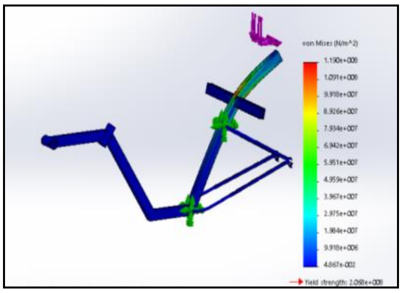
Figure 9:Maximum vonmises stress of 120MPa was obtained by performing top load analysis on the RPS

4.1 Side Load Analysis

The RPS is provided to protect the rider from impact with the ground in case of a vehicle roll over. This case simulates the case of vehicle falling side wards in case of a collision or imbalance. The seat belt mounting points are fixed and the side load of 1330N is applied from the side and the vonmises stress and maximum elastic deformation are calculated.

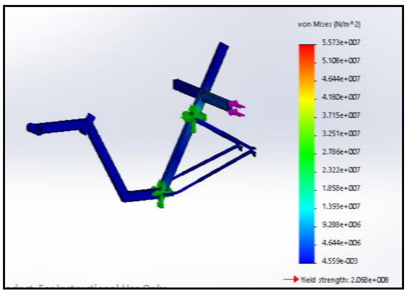
Figure 10: Maximum vonmises stress of 55.7MPa was obtained by performing side load analysis on the RPS

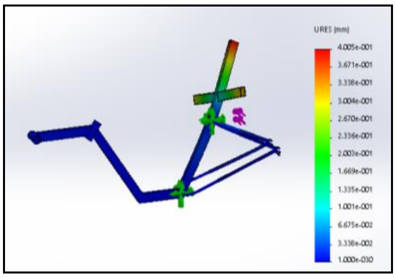

Figure 11: Maximum elastic deformation of 4.005mm was obtained by performing side load analysis on the RPS

4.2 Structural Analysis

4.2.1 Static analysis

The static analysis in the frame was done considering the weight of the rider and the loads acting on the frame due to initial pedaling (maximum force). The weight of the rider 800N was applied on the seat tube and fixed supports constraints were applied at the front and rear drop outs. The effort applied by the rider which is approximately equal to the weight of the rider, 1000N - bearing load was applied at the bottom bracket. This analysis has been conducted to find maximum stress induced at hip hinge point location and bottom bracket.

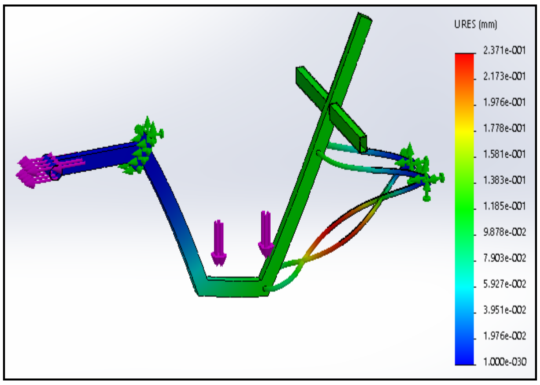

Figure 12: Maximum elastic deformation of 2.327mm was obtained by performing static structural analysis

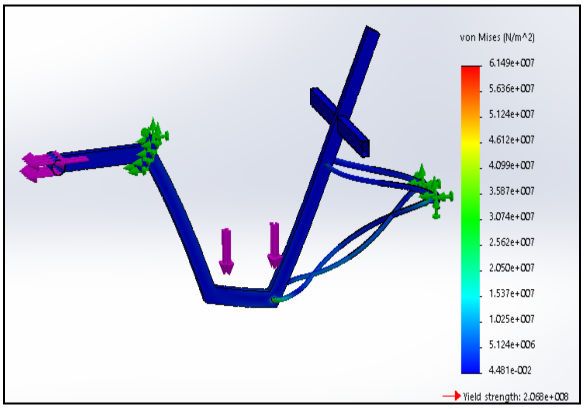

Figure 13: Maximum vonmises stress of 61.05MPa was obtained by performing structural analysis

4.2.2 Bump analysis

This case simulates the loading that occurs when the vehicle encounters a bump or pot hole. The front fork and handle assembly takes the shock and it is transferred to the head tube in the frame. A remote force (1300N) representing the impact is applied at the point at which the wheel axle is supposed to be present.

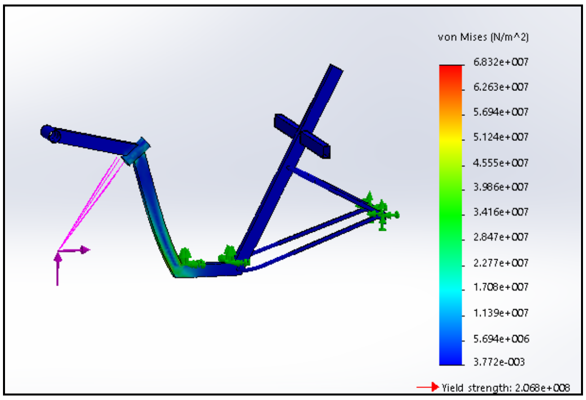

Figure 14: Maximum vonmises stress of 68.32MPa was obtained by performing bump analysis

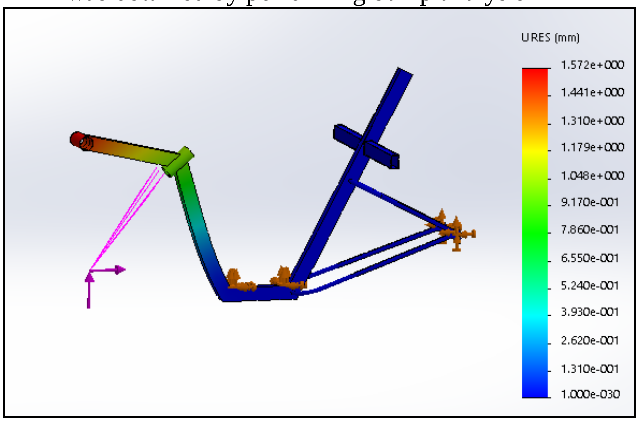

Figure 15: Maximum elastic deformation of 1.57mm was obtained by performing bump analysis

4.2.3 Analysis at maximum brake force

The case simulates the loading on the frame during the braking of the vehicle. The average speed of the vehicle is considered and the target speed for stopping is fixed and the braking force required is calculated and this force is transmitted through the axle, fork or chain stays. The seat post is fixed and remote force is applied representing the front wheel braking force being transmitted to the frame through fork. It has been observed that the stress induced is within the limits.

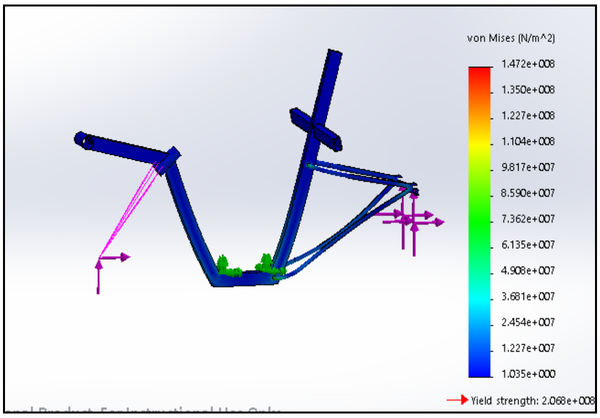

Figure 16: Maximum vonmises stress of 147.2MPa was obtained by performing brake analysis

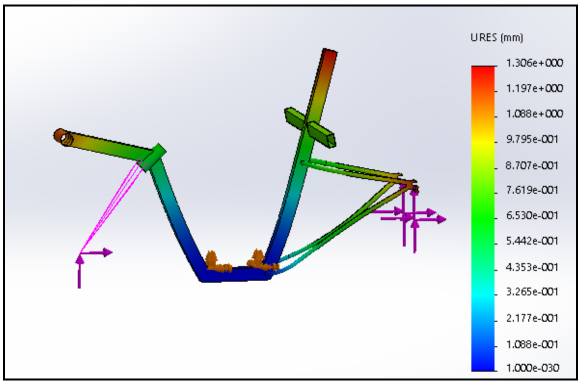

Figure 17: Maximum elastic deformation of 1.306mm was obtained by performing braking analysis

Table 4 : Result for static and dynamic structural analysis

Case	Max. elastic deformation (mm)	Max. Vonmises stress (MPa)	Factor of Safety
Static Analysis	2.327	61.05	3.38
Bump Analysis	1.57	68.32	2.93
Braking Analysis	1.306	147.2	1.404

5. CONCLUSIONS

The following conclusions can be drawn from the interpretation of the results obtained from the analysis, testing that were performed for the design and fabrication of the HPV.

- It has been observed that there isn't a significant deviation in the results obtained from analysis and testing.
- It is evident that few aspects of the vehicle can be ameliorated with the aid of effective fabrication techniques and the selection of high quality components
- Though the fairing was primarily designed to exploit the aerodynamic advantage – which was achieved; it also proved to be handy during minor mishaps which was an unforeseen advantage to the HPV; which was already equipped with many safety features.
- The ergonomics, efficient powertrain, steering, and braking design ensured that vehicle could be driven long distances without facing any discomforts.

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