Design and structural analysis of compound drive human powered vehicle

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1.Abstract:

Increase of the human population led to increase the use of vehicles for transportation from one place to other this leads to increase of pollution in environment by fossil fuels, Thus, one of the most sustainable solution is Human Powered Vehicle which can be used as economic and practical mode of every day transportation and to develop it by accounting the driver's safety and ease of ride to driver.

Human powered vehicles are becoming the future of sustainable mobility through various engineering developments happening rapidly. Human powered vehicles not only restricted land, they are being developed for air and water mobility too as Human powered aerial vehicles and human powered boats. The current paper is to discuss the compound drive human powered land mobility vehicle

Human powered vehicles can be designed to achieve much higher speed by applying engineering principles of design and material selection. As for any other vehicle the safety and ergonomics of rider during the mobility of vehicle is much required and adds more advantage to usage of HPV's.

2.Introduction:

The motto is to design the efficient, compact, high performance, and cost effective compound drive HPV to meet the demands of the industry and the standards while fortifying our vision and engineering principles. It is designed to create awareness how to build efficient and sustainable vehicle which does not cause the pollution to environment and to take the standards of human powered vehicle up a notch.

The designed HPV is a two-wheeler semi-recumbent with a rear wheel drive and front wheel steering. The vehicle being a semi recumbent, the overall drag area was reduced which further helps in attaining higher speeds and giving more comfort to rider. Aluminium 6061 T6 series hollow pipe has been used to design the chassis. Roll over protection system was designed for the enhancement of the rider's safety.

The two-sided sprocket, double chain, 7 speed transmission system has been decided. To validate the design several analyses were performed in ANSYS under various load conditions for different parts of the vehicle. Moreover, looking forward towards the development of a mechanical lever braking system that provides an optimum braking system.

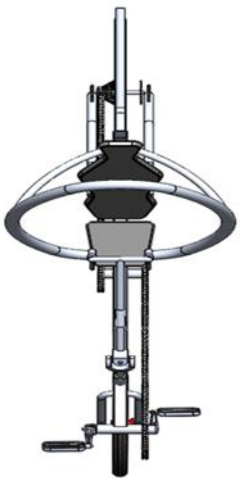
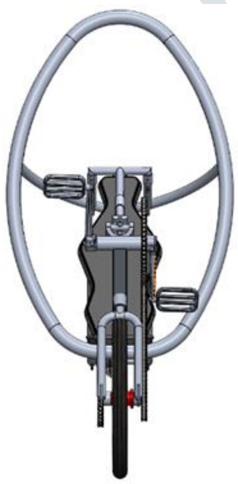
The major requirements assumed are safety, practicality, and efficiency, and to meet these requirements key engineering principles in the design have been implemented. Vehicle is designed to have incredible stability at exceeding speeds. High stability, good manoeuvrability, good speed, and with some storage space provided this vehicle is proven to be highly practical.

Goal	**Objective**
Weight reduction	To build light weight vehicle.
Vehicle speed	To improve the speed of the vehicle as per requirement, goal: 45-50kmph.
Safety	To improve the safety and comfort zone of rider.
Cost reduction	To Build vehicle efficiently by reducing cost.
Optimization in vehicle transmission	Reducing misalignment of chain drive by compound drive system.

Table 1: Goal and objective

3.CAD Model view:

3D -views:

	
Top View	**Isometric View**
	
Front view	**Side view**

4.Vehicle Description:

SYSTEM	DESCRIPTION
Main frame	Main Frame is designed to bear maximum load under variable loading condition and provide maximum factor of safety to vehicle. For mainframe Al-6061 T6 to maintain weight of bicycle and providing maximum strength.
Steering system	We are using centre steering with Universal joint mechanism. This steering system provides us efficient handling and control over vehicle at high speed.
Roll over protection system	The Roll over protection system has same material from of the main frame with the goal that it can be attached to the frame properly. We have utilized 38 mm external and 32mm internal diameter tube of Aluminium 6061 T6. The Roll over Protection System was planned considering the design requirements set by ASME HPVC rulebook 2020 and to improve the safety of the rider.
Drivetrain	Made effective changes to our drivetrain configuration. Obtaining an efficient start-up acceleration, better speed and durable setup are the main motives. To achieve the same, a combination of two-sided and double chain configuration has been incorporated. To get the desired gear ratio and transfer of more force, a chain ring of 60 teeth, a two intermediate sprockets of 36 and 28 teeth, a 155mm crank and a 7-Speed gear cassette are used.
Brakes	Decided to use rear disc brake as per our requirements.
Wheels and wheelbase	Dimensions of the wheels are 18-inch front and 26-inch rear. We used short wheelbase in our vehicle, taking into consideration factors like rider safety, stability, turning ease, drivetrain efficiency and comfort.
Ergonomics	Our vehicle is semi- recumbent so that it provides extra comfort to the rider. We designed our HPV in such a way that centre of gravity is positioned lower that provides easy handling for the rider.

Table 2: Vehicle description

5.Transmission:

5.1 Rear wheel Drive Vs Front Wheel Drive:

Properly designed drive train is essential for the HPV to reach high speeds. The drive train design requirements include reliability, effectiveness at varying speeds, efficiency and compactness.

Transmission selection	pros	cons
Front wheel drive(FWD)	• Compact • More efficient • Traction control makes suitable for snow conditions. • Only required small power transmission unit and results in the decrease of weight. • Less chance of failure	• Twisting of chain can happen, can interrupt with driver's legs, • Torque steer tendency. • The centre of gravity of vehicle is typically further than a comparable rear wheel drive.
Rear wheel drive (RWD)	• Twisting of chain is prevented • No torque steer tendency • Easy for drifting • Uniform weight distribution	• Long chain • Difficulty manoeuvring in wet conditions. • A large amount of mechanical losses • Long drive trains

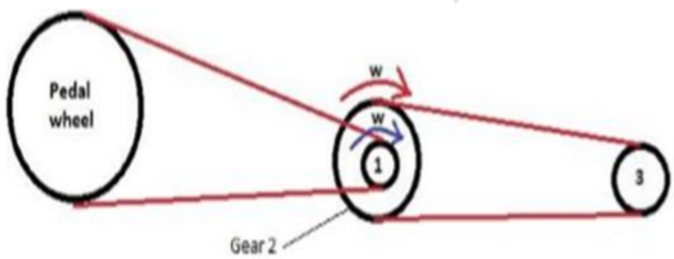
Table 3: Front Wheel Drive Vs Rear Wheel Drive

RESULT : From above table rear wheel drive is selected.

5.2 Transmission Selection:

5.2.1 Ideology:

Transmission is the transfer of power from source to a location where it is applied to perform useful work. In order to reduce the length of the chain between the driving sprocket and the Driven sprockets and get a better alignment of the chain, it was divided into two parts and use the **COMPOUND GEAR TRAIN** system. This system reduced the complexity of chain in issue length and also helped us to achieve the maximum gear ratio possible.



The drive has to be efficient, reliable and simple. The below mentioned made to choose multi drive:

1) As the single speed bicycle locks alternative gearing ratios it is less versatile, as it cannot be pedalled efficiently outside of its single gearing range.

2) Multi chain drive can offer better gear ratios possible.

3) Reduce Complexity of chain alignment.

5.2.2 Method:

Firstly one of the chain drive from front 60 teeth sprocket connects to middle 28 teeth sprocket connected to bottom bracket for the same bottom bracket 36 teeth sprocket is connected another chain drive is connected from the 36 teeth sprocket to rear 7 speed gear cassette(28-14) to achieve the minimum gear ratio.

- This reduced length of chain drive gives better alignment of chain and a greater speed.
- Better alignment and positioning of the chain system.

Front sprocket (Teeth)	**Intermediate sprocket 1(teeth)**	**Intermediate sprocket 2(teeth)**	**Gear cassette**	**Gear ratio**	**Velocity(km/h)**
60	28	36	28	2.70	21.34
60	28	36	24	3.21	25.23
60	28	36	22	3.50	27.36
60	28	36	20	3.85	30.45
60	28	36	18	4.28	33.86
60	28	36	16	4.82	38.12
60	28	36	14	5.51	43.59
60	28	36	11	7.01	55.30

Table 4: Transmission values after calculations

6. Analysis:

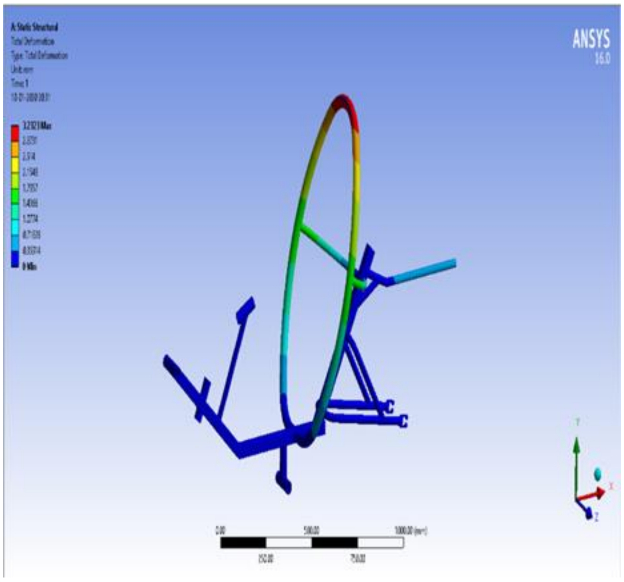
6.1 Roll over/Side Protection System:

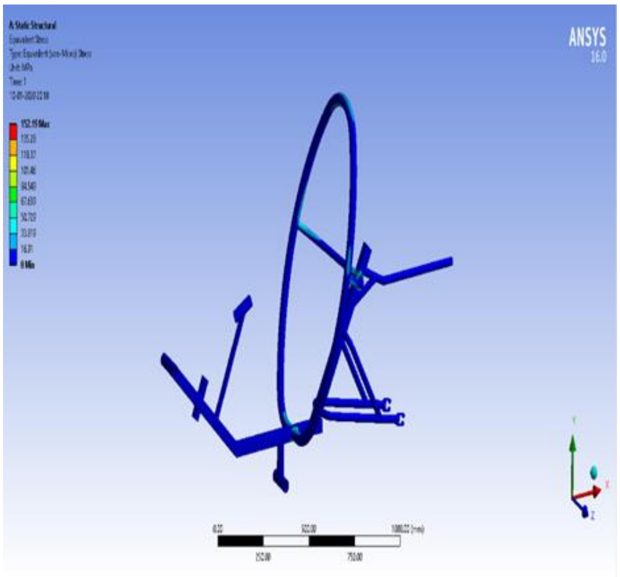
Objective:

Design a Roll over protection system in accordance with safety specification. The RPS must allow for a load path supporting the driver and retaining them from being ejected from the HPV in the event of a crash. This load path will be defined from the ground, to the outside of the vehicle body, through the structural RPS, through the safety harness, to the driver's body (centre of gravity).

6.1.1 RTLM (Rollover Protection System Top Load Modelling):

The model was designed according to the specified loads. We provided a fixed support at the rear wheel mounting points and constrained the head tube in vertical direction. A force of 2670N was applied at the top of RPS at an angle of 12degrees from the vertical as per ASME HPVC Rules 2020 specifications. Figure mentioned below represents result of this analysis.



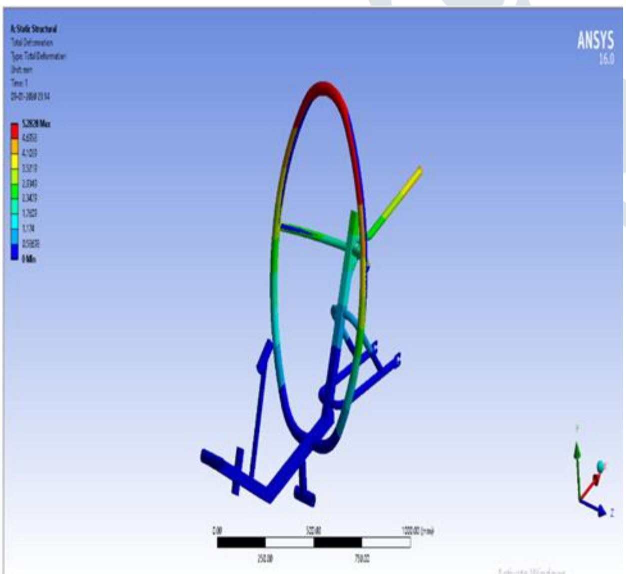


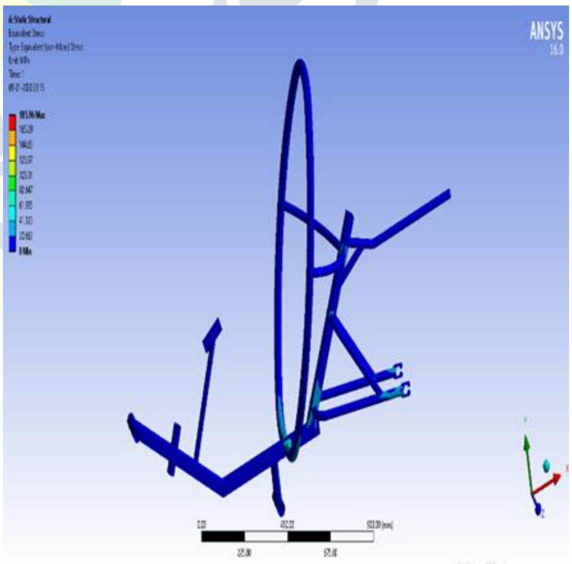
6.1.2 Top Load Result:

The result was obtained according to the defined parameters. A maximum deflection of 0.3 cm. was obtained due to the top load of 2670N applied on the RPS. The maximum deflection obtained is considerably less than the specified allowable deflection of 5.1 cm. The maximum stress observed was 152.19 MPa. The factor of safety came out to be 1.82 which justifies the top RPS.

6.1.3 RTSLM (Rollover Protection System Side Load Modelling):

To simulate the vehicle in a side crash, a load of 1330N was applied horizontally to side of the RPS at shoulder height as per the ASME HPVC 2020 rules specifications. Figures below display the result of analysis





6.1.4 Side Load Result:

The result was obtained according to the defined parameters. A maximum deflection of 0.52 cm. was obtained due to the side load of 1330N applied on the RPS. The maximum deflection obtained is considerably less than the specified allowable deflection of 3.8 cm. The maximum stress observed was 185.96 MPa. The factor of safety obtained in this case is 1.73.

Summary of Results:

Result	Allowed Deflection	Observed Deflection	Factor Of Safety
Top Load	5.1cm	0.3 cm	1.82
Side Load	3.8cm	0.52 cm	1.73

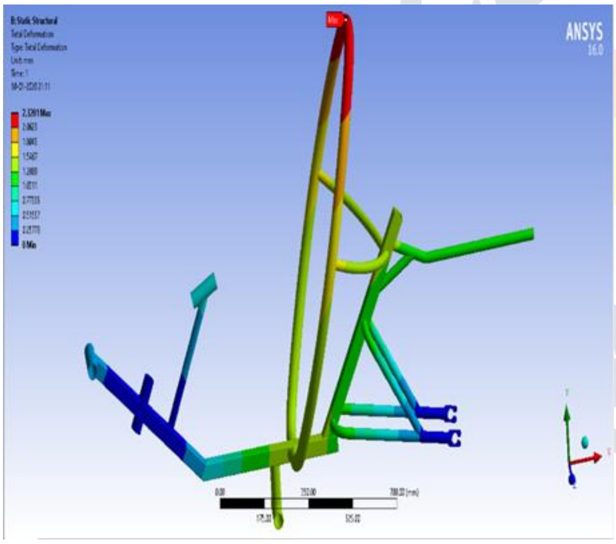
6.2 Structural Analysis:

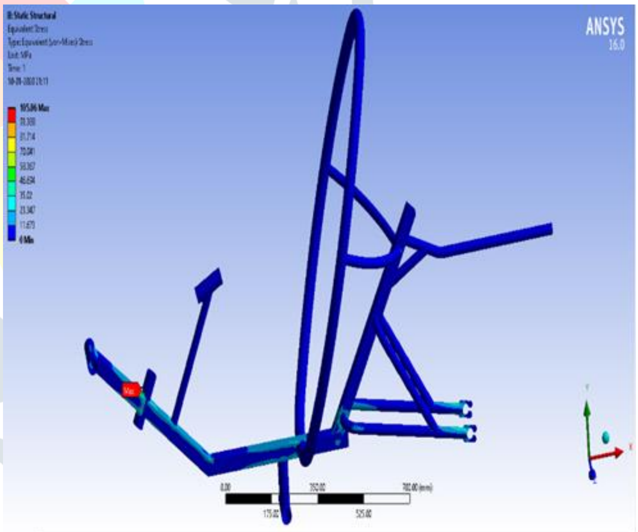
Objective:

To determine feasibility of frame design, reduce weight of overall chassis and detect critical points and also to validate the reliability and durability of structure. Various methods are used depending on type of structure. It also helps to understand the behaviour of chassis under all the load conditions.

Methodology:

Frame was modelled using Solid Works software and all required analysis was carried out using ANSYS software. The rear wheel mounting is constrained along with the head tube which is constrained in vertical direction. The load due to heaviest driver's weight is being applied vertically download and load of 1000 N was applied towards rear wheel to check frontal impact strength of frame. The results obtained are mentioned below.





Result:

The maximum deformation obtained for this case was 2.32 mm. There is no plastic deformation of chassis under defined loads. The maximum stress was 105.06 obtained at the. The factor of safety observed is 1.66.

7.Conclusion:

The frame designed is robust and satisfies given safety conditions and the compound drive system helps to achieve a maximum theoretical speed of approx. 55 kmph, which is beneficial speed of this kind vehicles. Apart from the theoretical engineering and simulation testing a physical performance review and dynamic testing is essential to conclude the final practical values. Improvements have to be done according value differences between practical and theoretical overall vehicle review. With all the improvements done, if required, these kind of HPV's will be most efficient, economical and ergonomically designed vehicle general purposes. Human powered vehicles will be game changers in the field of human powered mobility.

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