Design and Improvement of a Human Powered Vehicle (HPV)

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Abstract

A human powered vehicle (HPV) is powered without any external power source, such as a bicycle. The proposed design of the HPV uses a tadpole recumbent tricycle concept with two front wheels and one rear wheel. This configuration provides more stability to the driver. The design includes over-the-seat steering to maneuver the tricycle more efficiently and reliably. A shorter wheelbase is used to improve driver comfort and safety. Several other design parameters were incorporated to ensure ease of use. These parameters include mid-height riding position, strength, fatigue life, etc. The design process used methodologies such as quality function deployment (QFD) and analytical hierarchical processes (AHP) to finalize the conceptual design. The preliminary design used computer aided design (CAD) and finite element analysis (FEA) to analyze stress, deflection and fatigue. The HPV design incorporated performance criterion specified by the ASME human powered vehicle competition.

Introduction

The human powered vehicle (HPV) is a pedal powered mode of transportation; therefore, its success is measured by the effective transfer of pedal power to forward motion. Evidence suggests that despite having low speeds, aerodynamic drag has a significant effect on average speed and rider fatigue.[1] Human powered vehicles are available in many different forms: bicycles, water-based vehicles such as submarines and boats, and even some airplanes are operable by human beings. Usually, if a human powered vehicle utilizes a pedal driving system that has three or more wheels, it will typically lie in a supine position.

The inspiration for this project came from the HPVC (Human Powered Vehicle Challenge), which is an annual competition held by the ASME (The American Society of Mechanical Engineering). The main focus of the competition is to advance the technology. Over the last decade, bicycling has become less popular, but more visible. The bicycle market in the US is not growing, yet it has the potential to become far more profitable. While bicycling faded as a pastime, it grew as a sport.[2] Regardless of this fact, there have been many studies showing that there is still an interest in supporting those that uses their bicycles for an economic and/or transportation need.

Literature review

Many variations of human powered vehicles attempt to independently combine arm and leg power. This is an advantage for transportation purposes and also produces better overall exercise than is possible with pedal-crank bicycles.[3] The difference between the upright bicycle and the recumbent bicycle is that with bicycles, only the legs can be exercised, but for the recumbent bicycle, 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] The position of the rider with feet forward and head nearly erect is more comfortable than a stomach-down position and is much safer in a collision than a head-forward position. In addition, the rider can exert greater pedaling force than is possible in the position used with a conventional bicycle.[5] The seating position in a HPV plays an important role. The reclining position further backward allows a further reduction of frontal area thus lowering drag. Additionally, the reclining position further backward may provide better physical advantages for endurance as indicated by observation at a race event.[6] By carefully choosing the seating position, it can ensure efficient use of the operator's arm and leg strength through cantilevered leverage arms and foot pedals mounted on a set of motive members.[7] In addition to these decisions, one important objective to achieve is to provide an improved human powered recumbent bicycle that is simple to manufacture, strong, lightweight and is adaptable for a wide range of uses, including exercise/recreational use, racing, and utility vehicle, the latter particularly for third world countries.[8]

A few ideas may influence the design of this vehicle. In the case of another team that built an efficient human powered vehicle, the objective was to successfully transport the operator using special hydraulic systems. The human powered hydraulic transportation system was designed to move a single person in most energy efficient manner. A test system was utilized to ensure optimum performance of all major components. The kinetic energy lost during downhill motion was captured, stored in a hydraulic accumulator and later utilized to assist uphill motion.[9] It's ideas like these that are welcome to the competition, especially during the innovation event, where the innovative ideas are encouraged.

Another factor for operator and vehicle interaction was considered. In the Road Event of the HPV competition, the keys to success are vehicle reliability and endurance training of riders. Vehicle reliability has proven to be a large factor due to the significant amount of time lost during vehicle failures and vehicle crashes. These parameters are more immediately associated with the mechanical design of the vehicle than they are with race strategy. As a result, the race strategy for the road race will focus on optimizing the endurance performance of our riders through estimates of power output and through correlation to cycling performance data.[10]

Methods

There were a multitude of designs that could have been chosen in order to fulfill each of the desired requirements. Each choice had its own set of advantages and disadvantages and many of the choices were made based on personal preferences.

The wheel configuration included many variations. There could be the conventional two wheels like that of an upright bicycle, as seen on the leftmost image of figure 1, or there could be two front wheels and one rear wheel, called a tadpole tricycle, as seen on the right most image of figure 1, or two rear wheels and one front wheel, called a delta tricycle, as seen on the middle image of figure 1. The tadpole was chosen due to the fact that it better at cornering and is very stable which is very important for the competition. Although the delta and two wheeled configurations offer more speed, speed is not as important as that is only one event and the bike will not be going very fast either. Thus, it was decided not to focus more on speed that other parameters such as stability.

Figure 1: From Left to Right: A two wheeled recumbent bike[11], a delta tricycle[12], and a tadpole tricycle.[13]

The next choice that was made regarded the type of steering used. The two types of steering would be over seat steering, as seen on the left image of figure 2, where the handlebars are positioned above the driver, and under seat steering, as seen on the right image of figure 2, where the handlebars are positioned to the side of the driver. This choice was made due to personal preference. As none of the members have experience with riding a recumbent vehicle, it only seems necessary to choose the steering choice that allows for easier learning.

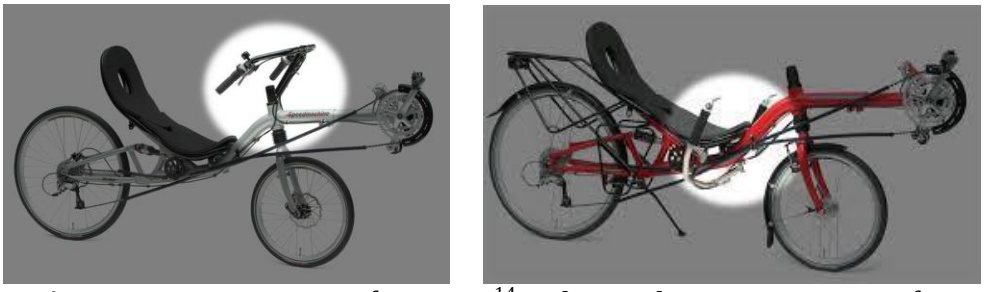

Figure 2: An over seat steering configuration[14] and an under seat steering configuration.[15]

The next choice revolved around the size and length of the bike, also called the wheel base. The options range from short wheel base, shown in the leftmost image in figure 3, to long wheel base, shown in the rightmost picture of figure 3, and the choice depends mainly on the operator. Thus

choice was based on the size of the rider(s) and with one required female rider and one female that is a part of the group, the bike must be designed are that member. Due to the size of the female member, the short wheel base was the best choice.

Figure 3: Three recumbent bicycles by increasing wheel base, including short wheel base,[16] medium wheel base,[17] and long wheel base.[18]

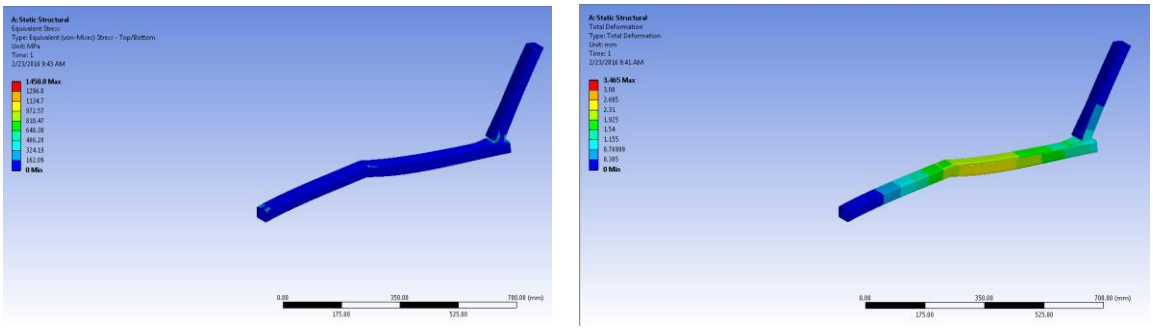

Figure 4: ANSYS models of the frame of the tricycle showing the deformation and stress

With the use of FEA (Finite Element Analysis), it was found that, with the type of steel that we were using, 1015 steel, there would be little stress in the frame and there would not be any significant deformation. These results let the team know that the design was safe.

Design Tools/Processes

This bike will be able to be built using traditional tools and machining methods. Since sustainability is an ever-growing trend and goal in manufacturing, as many parts as possible will be salvaged from other traditional two-wheel bikes. A new frame will be constructed out of square stock steel and the salvaged materials will be connected to the frame using welds. It will be vital to make sure that all measurements and angles are cut with as much precision as possible as there is little room for adjustments given welds of a permanent nature. Some wooden jigs may need to be assembled in order to give a stable platform at correct angles for welds. Most cuts that will be required should be able to be accomplished with a metal band saw and a reciprocal saw with a metal cutting blade should be sufficient for any cuts that the band saw can't make. Components that need to be connected but also with degrees of freedom such as rotation for wheels/sprockets, etc. will be assembled using bushings and bearings placed in cylindrical steel stock that has been welded to and, therefore, is part of the frame. A paint will most likely be applied to the frame in hopes of preventing rust or other wear. As with any projects, there will

undoubtedly be final minor tunings to the design in order to make sure that everything aligns and works to its optimum ability.

Results

There are a multitude of results that the vehicle is expected to meet. The objectives that the bicycle should meet are provided by the organization. Such objectives include: 1) coming to a stop from a speed of 25 kilometers per hour in a distance of 6 meters, 2) having a turning radius of 8 meters, 3) remaining stable when traveling 30 meters in a straight line at a speed of 5 to 8 kilometers per hour, 4) surviving a load (force) of 2670 Newtons that is applied to the top of the vehicle, 5) surviving a load (force) of 1330 Newtons that is applied to the side of the vehicle, and 6) having an ability to hold 1 kilogram of cargo. These constraints will cause the bicycle's appearance to change to accommodate these constraints. To make sure the group follows these constraints we are going to run three different tests. The first of the three analyzes the braking of the human powered vehicle, in order to test the vehicle the group is going to be in an open area and draw two lines an arbitrary line and a second line to make sure the vehicle meets the criteria, this will test the stress of the brakes. The second test that will be analyzed is the making sure the vehicle can survive a load of 2670 Newtons applied to the top of the vehicle, the group will apply a total of 273 kilograms to the frame of the bike to test the fatigue that could be caused to the frame. The third test will also test the fatigue of the frame by applying 1330 Newtons of force to the side of the vehicle. These tests will allow the group to analyze the stresses and fatigue that could be caused to the vehicle.

Conclusion

The product that will be designed is a recumbent bicycle based on the rules and regulations of the HPVC (Human Powered Vehicle Competition). The bike to be made is called a tadpole tricycle, which means that there will be two wheels in the front and one wheel in the back. It will equipped with over seat steering and a short wheel base and will be in the mid racer category, meaning it will not ride too high or too low.

The next step that must be taken is to actually build the tricycle and test it according to the constraints imposed by the rules of the competition. It is nice to have it designed beforehand, but it will not be a finalized product until it is tested and can meet all of the requirements expected. In terms of commercialization, this product would have to compete with other recumbent bicycles made by professionals who have much more experience in this field. However, unlike the other recumbent bicycles, this product will include an optimal design that can provide more speed, stability and, most importantly, safety. There is also the innovation of the bike, which is to include an adjustable seat so that riders of all sizes can have equal access to it, which is what a lot of recumbent bicycles are lacking.

Design refinements could include a different steering system as the rack and pinion system may not be the best choice for this type of bike. A different steering system may offer less weight, be more comfortable, or many other qualities that were given up due to this design. The innovation of an adjustable seat may also be tweaked as it is an idea that is not common in recumbent

bicycles. With a little more commitment and time spent on developing the concept and getting it to fit better, it could be a very fruitful concept.

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