Hydrogen-Electric Motorcycle

Final Project Report

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Abstract

"The number of vehicles on our roads and the number of miles driven by those vehicles are growing at an accelerating rate, resulting in increased national petroleum consumption and air pollution." (Sutula, 2) In response to these problematic trends, new vehicles are being introduced to achieve better fuel efficiency while producing fewer harmful emissions. In view of this need, this project has worked in collaboration with Electrion Inc. to develop a personal transportation device using hydrogen, a zero-emissions fuel.

The main focus of our team lied in the mechanical and electrical aspects of a small motorcycle, or scooter, rather than the implementation of the hydrogen fuel. With a prototype of the scooter provided for us by our industry contact, Dr. Joseph Kejha, we have made improvements to his design in order to solve several performance-limiting problems. The bulk of our work falls into three main areas of design: the body, the steering, and the electrical system.

The body design, or chassis design, was accomplished using finite element analysis software, in which we were able to assess our material choice and analyze our frame design in order to construct the most efficient body. Our steering system will simply improve upon the present steering column and its actuation mechanism. The electrical aspect of this project incorporates the design of a system integrating Lithium Polymer batteries with the electric motor and overall control system.

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Acknowledgements

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1. INTRODUCTION

1.1 Description

The problem presented to us by our industry contact, Dr. Joseph Kejha, was to find a way to improve upon the basic idea for a hydrogen-powered scooter prototype he had already created. The main areas which needed improvement included the chassis, the fairings, the steering system, the suspension system (or lack thereof), and the electrical system. The foremost problem with the chassis design was that the sole central shaft was experiencing torsion with the onset of the scooter's motion. The effects of wind resistance on the chassis only intensified this problem. Our goal was to eliminate this problem, while maintaining an extremely lightweight frame. We also intended to design fairings which would provide a protective plastic shield for the scooter as well as improve aerodynamics and aesthetic appeal. The problem to solve with the steering system was to find a way to provide ease of use for the rider as well as good maneuverability for the scooter itself, while improving upon the less-than perfect actuation mechanism that was in place. As for suspension, the scooter originally had no shocks; therefore, we intended to design and implement an effective suspension system. The electrical system of the prototype presented to us also needed some improvements. A high energy and power density electric system was desired by our industry contact.

Our original objectives were to create a recumbent scooter that would satisfy the following specifications: 1) to have a dry weight of 100 lbs. or less; 2) to accelerate from 0 to 60mph in 10 seconds or fewer; 3) to cost less than $3500 for production; 4) to maintain stability for a rider up to 230 lbs.; 5) to have a stress safety factor for the frame of at least 2.0.

As the project progressed throughout the year, though, we realized that due to the magnitude of the work before us, we would have to set aside some objectives in order to focus on the other, more important design aspects. Therefore, our intentions for this project became threefold: first, to design a frame for production that would be both lightweight and durable; second, to implement a method of steering that would improve maneuverability and ease of use; and third, to create a method to control the voltage both charging the batteries and driving the motor.

The body design, or chassis design, was accomplished using finite element analysis software, in which we were able to assess our material choice and analyze our frame design in order to construct the most efficient body. Our steering system will simply improve upon the present steering column and its actuation mechanism. The electrical aspect of this project incorporates the design of a system integrating Lithium Polymer batteries with the electric motor and overall control system.

1.2 Literature Review

Hydrogen Fuel

For quite some time scientists have been researching different methods to power automobiles so that they are not only more economically efficient but also environmentally cleaner. The more popular methods that have been pursued include deriving power from electricity, natural gas, hydrogen, nitrogen, and numerous hybrids using two or more of the aforementioned means.

Many different manufacturers currently have electric vehicles available and gas-electric hybrids that use a small generator to charge the battery. These electric vehicles have a relatively short range and require long charging time between uses. A few manufacturers have been experimenting with hydrogen to power assorted vehicles. Currently there are two main methods of implementing hydrogen power for transportation functions: first, using a hydrogen fuel cell to create electricity to run a motor, and second, converting a gasoline engine to simply run on hydrogen instead.

The first of these methods, the hydrogen fuel cell, is desirable in that it is truly a zero emissions vehicle, pure water being the only byproduct. The problems involved with using a hydrogen fuel cell are the immense cost of the cell itself, and the complications of efficiently transferring power to the wheels. Until more efficient and less expensive methods of using hydrogen fuel cells are developed, some manufacturers have decided to begin experimenting with hydrogen internal combustion engines. The benefits of this method include reasonably simple implementation, results that closely rival that of gasoline and diesel engines, and far better emissions than both gasoline and diesel (although it is not a zero emissions vehicle).

Automobile manufacturers such as Mazda, Ford, and BMW are pioneering leading edge technology involving hydrogen internal combustion engines. Each of these three manufacturers has been working on and testing adapted versions of some of their own automobiles that run on hydrogen. BMW’s solution to the problem is to make simply convert their standard eight-cylinder engine to run on hydrogen and to store the hydrogen in the trunk in two large tanks. They claim that their hydrogen versions can perform very similarly to the gasoline counterparts, with only slight drops in horsepower and torque.

Frame

In recent years, there has been a revolution in the development and use of new materials for building bicycle frames. It wasn't that long ago that frames were made out of cast iron or even wood. Today, bicycles are made out of exotic materials such as titanium, aluminum, and carbon fiber. Bicycle frames in the 1990s are lighter and stronger than ever before.

When a bicycle maker chooses a material to make a bike frame, he or she usually considers the following properties of the material: elasticity, yield strength, and ultimate strength.

Materials

Steel: Steel has good ultimate strength, with a much lower yield strength. This is good, since it means that a steel frame will bend well before it breaks, lessening the chance of a disastrous crash. Steel also has good elasticity. This combination of properties has made steel a longtime favorite of frame builders. Steel's only drawback is its relatively high weight. "Steel has been around a long time. It's probably the most researched, well known, and the most used material in just about every industry. It's the most tunable, in the sense that if you want to tune a frame the way someone tunes a piano, you have a really great selection of tubes that you can select from." (Paolo Salvagione, modern frame maker) Steel is also generally the most affordable of the materials listed here.

Aluminum: Aluminum has recently become a choice material for frames, because of its very light weight. However, aluminum has a yield strength very close to its ultimate strength. Therefore, it is quite brittle, and prone to breaking. This has many dangerous consequences for the rider of an aluminum bike, so frame makers have responded by over-building aluminum bikes with very large tubes and thick welds, to lessen the chance of frame breakage. "Aluminum is an interesting material. You can't really let it flex, because the more it gets to bend the quicker it reaches the end of its life. That's why you see a lot of aluminum frames today that have very large diameter tubing. That's to limit the flexing that happens as you ride the bike." (Salvagione)

Titanium &Carbon Fiber: Other materials, like carbon fiber and titanium, have light weight, high elasticity, high ultimate strength, and relatively low yield strength. Frames made of these materials need to be designed well, in order to be stiff enough to resist pedaling forces. However, such frames are extremely light and resilient. One drawback is that these materials are extremely expensive, putting carbon-fiber or titanium frames out of reach for all but the wealthy or the fanatic racer.

> **Titanium:** "It seems that titanium is the material of choice. It has a great strength-to-weight ratio. You don't need to paint it and it looks good over a long period of time. It has forgiving qualities when it collides with other things. It tends to return to its original shape," explained Paolo. The cost however is another matter. Titanium tubing can cost up to 15 times more than steel.
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> **Carbon Fiber:** "It's the boat builder's material, as a friend of mine calls it. It's really interesting because unlike the other materials, where you have to draw it into a tube or forge it into a section, with carbon you can literally change the direction of the fabric in a certain area which will affect the way a load comes through that area. So in a sense when you build a carbon frame you feel like a tailor." (Salvagione)
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> **Welded Carbon Fiber:** A welded carbon tube is braided from carbon fiber, one of the strongest materials used in bicycles. The tube is then impregnated with aerospace-grade epoxy. The frame successfully avoids any kind of lugging and the problems associated with lugs.

Design

The most popular frame design is known as the diamond or double-triangle. This design has changed very little since the advent of the safety bicycle in the 1880s. Paolo explained, "It's proven to be a great use of materials, great for bracing angles, great for strength; it lends itself to being beat up pretty hard and still being ridable." The strength of the design comes from the triangle shapes that make up the diamond design. As Paolo explained, "Structurally, it's quite impressive. If you look at engineers playing with structures, they tend to come back to triangles and since the bike is basically three triangles, it works out to be a pretty strong structure."

While the diamond design is the core of most bicycles built today, some frame builders are experimenting with new variations on this classic design. For example, some carbon-fiber frames are being made with oval tubing, making the bicycle more aerodynamic. New full-suspension bikes have altered the diamond design to allow for a large shock to be mounted on the seat stem. However, most changes to the design are more subtle and have to do with maximizing performance for different types of terrain or uses.

Suspension

Recently, with the soaring interest in mountain bikes, designers have once again been exploring suspension with a vengeance. The rocky terrain covered by mountain bikes makes suspension desirable once again. However, suspension systems often bring added weight and odd steering and pedaling characteristics. The advent of new ultralight materials, combined with refined designs, have made suspension forks almost ubiquitous on the modern mountain bike. Even "dual-suspension" has been attempted, with the goal of suspending the rear wheel without altering the action of pedaling. Many good designs have appeared, ranging from the venerable pivoting rear triangle to a design where the riders sits on a carbon- fiber beam levered out from the head tube. Though the added weight of these bikes is still a problem, they have earned a growing following for their comfort and handling.

Stress on the Frame

Bicycle frames have to be built to handle a variety of loads. First, the frame needs to support itself and other components of the bicycle. These are considered static loads. In addition, the frame needs to be able to handle the cyclist's weight, the forces of pedaling and braking, and the effects of the road's surface. These are dynamic loads; they are the most problematic for a frame builder since, as the name implies, they move and vary in intensity.

Frame builder Paolo Salvagione explained which areas of the frame take the most stress. "Think of a fork as a crowbar on a head tube. Not only do you have the length of the fork which tends to be 16"(40.64 cm), but you also have half of the diameter of the wheel which is another 13"(33.02 cm), so you have a pretty long crowbar there. So if you're riding down a hill and you hit something really hard you have a long lever working on a very small tube. That tends to be an area where a phenomenally large amount of energy needs to be dispersed." Paolo went on to explain that the energy produced by such a collision could throw the cyclist or damage the tube. Most frames are engineered to handle less common events like this.

The other areas of a frame that Paolo was concerned with were the ones that handle stress over time. These areas are common near the chain line. The continual pedaling action exerts forces on the frame. In addition, these areas must also continue to handle the other static and dynamic loads exterted. Paolo uses his experience and engineering knowledge to make sure his bicycles can handle whatever comes down the road.

Recumbents

Recumbents hold many speed and endurance records and are quite comfortable to ride. Recumbents are so efficient that many races do not allow recumbents to enter for fear that the cyclists on the traditional safety design will be at a disadvantage. There are a few disadvantages to the recumbent design. One is the cost; recumbents are not mass-produced and cost more than safety bicycles. In addition, recumbents are harder to see on the road--most use an orange safety flag so automobile drivers can more easily avoid them.

Wheels

Minimizing the weight of the wheels is extremely important in bicycle design. Weight is so important because each time you push the pedals, you have to accelerate the weight of the wheel both forward and around its center. In other words, the wheel undergoes angular and straight motion simultaneously. You can see this when you ride--the front tire of your bicycle rotates while it moves forward along with you and the bike.

Brakes

Coaster Brake: The coaster brake is still in wide use throughout the world and appears in a number of less sophisticated bicycles like cruisers and utility bicycles. Coaster brakes also appear on some children's bicycles and tricycles. The coaster brake works by reversing the motion on the pedals. The brake mechanism is inside the hub of the wheel and pushes outward on the hub, creating friction and slowing the bike. This brake is particularly strong and tends to "lock up" or skid the rear wheel when engaged.

Caliper Brakes: The most popular brake for road and mountain bicycles is the caliper rim brake. The cyclist engages these brakes by pulling on levers which pull cables, forcing pads or shoes against the inner rim of the front or rear wheel. Caliper brakes are lightweight and inexpensive but they are not without problems. During wet weather it may take twice the distance to stop as it does in dry. The water acts a lubricant on the sides of the rims. During very long downhills the rims can heat up, even to the point of melting a hole in the tire's inner tube.

Drum and Disc Brakes: Drum and disc brakes are less common braking systems for bicycles. Drum brakes work by applying friction from a pad inside an enclosed drum. The drum is part of the hub of a wheel. These type of brakes generate a great deal of heat and warning labels appear on the outside of the hubs warning the rider not to touch the hub for a time after the brakes have been applied. Disc brakes work very much like caliper brakes, with a separate disc attached to the hub. The main benefit is that the disc is away from the wheel spray and consequently any liquid, dirt or other materials. Both of these types of braking systems add more weight to the bicycle, but drum brakes are especially heavy. These types do appear on professional downhill bikes where the added weight is not a concern and the added braking power is essential.

1.3 Solution

For the chassis, we chose to use a steel frame for the prototype construction because it was easier to weld together, the strength to weight ratio was comparable to what we designed for, and cost was relatively cheap. For the steering system we chose to change the setup idea given by Dr. Kejha and implement a different under-the-legs setup. We chose this option for many different reasons: construction was easier, the steering handlebar was not in the way of the legs, the driver's vision of the road in front of him was increased, the ease of getting on/off the bicycle was increased, and the precision of the steering was improved. For the electrical system, we chose to implement a charging circuit for lithium ion polymer batteries, because these cells have a high electrical density, and have a higher voltage and current as well. For the brake system, we upgraded the standard mountain bike-style cantilever brakes to new mountain bike-style disk brakes mounted on 20-inch wheels, because we needed a higher stopping power to the wheels because of the higher speed and mass. For the suspension system, we chose to use a mountain bike fork with dual shocks for the front. For the rear suspension, we designed a swing arm that continued through the pivot point on the frame to a coil over shock mounted on the end. This design serves a dual purpose: to move the support spring inward toward the center of the frame where the forces could be distributed more evenly, and to increase room for the electrical drive motor on the wheel side of the swingarm. For that drive motor we were given a Lynch motor and for the Gasoline engine we were given a Honda 1.5hp engine, which would drive the 48-volt generator, which we were unable to obtain. We chose to use a belt drive system from the Lynch motor to the rear wheel. The seat and front footrest were used from the prototype given to us by Dr. Kejha.

2. DESIGN PROCESS

2.1 Chassis:

In order to provide a stronger frame that would better resist torsional motion, we spent a lot of time focusing on how we could take the existent central shaft of the prototype and alter it to make it stronger. We considered increasing the diameter of the tube or increasing its cross-sectional thickness, which, in both cases would simply provide for a stronger central shaft. Another option we deliberated was to use square tubing, which would be less likely to succumb to torsional motion. Finally, we considered welding two tubes together to create a double shaft that would be both stronger and more resistant to torsion. At this point, none of our ideas really stood out as exceptional, so we decided to approach the problem from a different perspective, completely redesigning the original frame. We decided to opt for a three-dimensional pyramidal frame design. (See Fig. 1) With our design, the problem of torsion of the chassis in response to motion and wind should be eliminated. Using I-DEAS, a finite element analysis program, we were able to analyze the scooter under four different loadings, including a frontal impact, a suspension compression impact, a rear side impact, and a mid-frontal side impact. By placing static loads and forces on the frame from different directions, and constraining the frame in strategic locations so as to maximize frame damage, we simulated dynamic forces encountered when the scooter is in motion. (See Appendix B) I-DEAS also allowed us to determine what size tubing would be most efficient for each member of the chassis in order to absorb the stresses inflicted upon it when in motion. In the practical realm, we constructed several different models of the scooter so as to be able to observe weak points and get a better feel for the design. First, we built straw models which proved to be helpful in simulating torsion and constructing a design that would better resist this twisting motion. When we decided on a design we were confident with, we built a prototype out of EMT. This provided great assistance in determining the layout we would use for the electrical components. We were also able to see the need to make minor adjustments to the frame so as to better accommodate the rider and the electrical components.

When implementing the rear suspension system, we were faced with the difficulty of shock placement on the swing arm. With the motor being mounted directly to the swing arm, little room was left for the shock mount. Initially, we made designs to mount the shock on a cross bar between the two swing arm members and attach it to a single vertical bar which would act as the back support. However, space considerations with the motor mount meant that we would have to extend the length of the swing arm beyond a desirable length to maintain a minimal wheelbase. Also, we realized that the forces absorbed by the shock would be transmitted solely into the midsection of the vertical member, which would provide an extremely weak point of our design. After further consideration, we decided to extend the length of the swing arm beyond its pivot point, and mount the shock from the end of the swing arm, attaching directly to the bottom point of the triangular base. (See Figure 2) With this setup, the forces absorbed by the shock would be transmitted into our greatest point of strength on the chassis.

2.2 Steering

Dr. Kejha presented our team with certain problems associated with his existing steering design. The two main problems were maneuverability and stability. One solution we brainstormed was that of a geared system of steering. This solution was not carried out because geared systems can lose precision or “tightness” in certain applications and over periods of use. The next idea was to use a simple motorcycle fork and handlebar setup. The problem with this idea is that the recumbent style riding would create awkward steering motion, thus not meeting our solution of advancing the maneuverability and stability of the scooter. Another idea was to make the frame and steering system longer by moving the front wheel forward, away from the driver. This would give a longer wheelbase, better stability, better handling, and possibly a more comfortable ride, as bumps would be absorbed well and there would be less vibration transfer to the driver. This setup would include making the steering handlebars longer to reach the driver's arms and clear the feet and legs of the driver. Due to the fact that the feet and legs are very near to the front wheel, a quick solution would be to have the feet and legs steer the vehicle. This would result in easier construction and less material. However, operation would consequently be more difficult. For instance, pulling out from a dead stop while trying to steer either direction when feet are needed to balance the bicycle standing up is not easy maneuverability. (See sketches of foot steering)

Some important aspects of the steering system are the turning ratio, shaft/fork angle, length of fork, and length of handlebars. Our first dilemma was what type of handlebars to use. Three possibilities were looked at, including a round automotive-style steering wheel, U-style steering typically used in airplanes, and bicycle-style steering handlebars. Dr. Kejha had previously stressed to us his desire for airplane-style steering. This setup would include changing the existing vertical fork shaft with horizontal steering plane of motion to a more vertical plane of motion steering wheel connected to a series linkage of shafts and universal joints. After careful thought of the complicated nature of the series linkage steering, our group decided that the bicycle-style steering with fewer links and the horizontal motion plane would be not only ideal for construction, but better for the operator, in that the motion is similar to that of a normal bicycle. Two vertical handles would be mounted to the ends of the handlebars, which the operator would hold onto. Hence, leaning and balance would not be required learned motions to new riders of our scooter. Our steering design includes a handlebar mounted underneath the operator's legs in the main section of the frame behind the steering fork shaft. A horizontal connecting rod with pivot joints on both ends will make the linear motion of the handlebars be turning motion of the fork shaft and the front steering wheel. (Note: At first, we planned to utilize two connecting rods, one on either side of the handlebars, but we realized that turning ratio adjustment would have been difficult with the dual rods. Both rods would have to have been the same distance from the pivot of the handlebars and from the fork shaft pivot. One connecting rod can easily be finely adjusted.) A bracket mounted to the fork to mount the connecting rod to is also required. Adjustment of the steering ratio of the bike will be made by moving the pivot point on the handlebars inward to reduce the turning ratio and visa versa. This will be a set turning ratio that can only be adjusted during non-operation. The idea of variable ratio steering was considered, which would create stability at high speeds and tight turning radii at lower speeds when needed. The team needed to concentrate on the main frame of the scooter and other analysis of parts so the simple linearly proportional steering setup was chosen. Dr. Kehja did not specify a turning radius desired, but did specify a wheelbase as given by his prototype. He did specify wheel sizes for front and back as 16 and 20-inch diameters, respectively. During our research we found that we could not obtain a front steering fork for a 16-inch wheel with the desired suspension shocks. We could, however, obtain a 20-inch fork for our application, so we decided to use the 20-inch diameter wheels.

The caster angle of the steering tube on the main frame of the scooter is important to the maneuverability and stability of the steering system and the balance of the scooter. This steer tube will have a bushing pressed into each end along with bearings, and the fork shaft will run through them. A nut and washer on the top will hold the fork shaft in the steer tube. We had to obtain a steel tube to make this steer tube. This tube was welded to the main frame rails and then machined on the inside to the diameter needed for the kit. The order of this process was done to eliminate the possibility of warping the tube's inner diameter from welding. The steer tube was welded on the front of the frame perpendicular to the top frame rails. The position of the top frame rails is 10 degrees below horizontal from front to back. This will create a positive caster angle of the head tube of 10 degrees. This caster angle will make the tire contact the surface of the road a distance of 1.75 inches from the hypothetical point that the fork shaft creates on the surface of the road. This will create a "caster effect," which will make the scooter more stable during operation and keep the steering going straight with little or no input from the rider.

We learned from designing the steering system for this scooter that simplicity and ease are very important. We were limited to one wheel, which steers the scooter, instead of a dual front wheel tricycle. This basically eliminated the need for a camber angle or made it zero degrees. We were limited in the space for operation. The wheel needed to be positioned under the rider to maintain the wheelbase. Dr. Kejha's design of an airplane style steering would place the steering system on top of the rider's legs, which would be in the way of the rider's legs. To get the wheel out of the way of the rider's legs it must have been raised, which would significantly reduce the vision of the rider and the precision of the steering. Hence, the under-the-legs system was used in the design. This setup also utilized better range of motion of the arms while in the sitting position. It is easier to push or pull horizontally front or back on handlebars than push or pull vertically on the airplane wheel.

2.3 Electrical System

Our electrical system is comprised of five major categories: the generator, the batteries, the charging circuit for the batteries, the motor and the motor controller. The generator proved to be a bit challenging to find. We needed to select a generator that would sync well (1:1) with the 1.5hp Honda engine we already had and more importantly, it would have to provide a steady 48v. The E-Cycle MG13 was implemented because of its 48V capability and inexpensive price tag.

Now with 48V in the system, we would need a 48V battery pack. Also, to get the estimated power required for driving, we would need a battery pack to provide 30A of current. For this pack we chose to use Lithium-Polymer cells. This decision was based on the extreme electrical density that these cells have, as well as their "no memory" capability. However, there is one disadvantage to the cells; if charged beyond maximum capacity, they will be destroyed and perhaps inflame. With this in mind, we decided to look into the possibility of Ni-Cad batteries as well as some other newer types of batteries. With our strict weight constraints, the LiP cells appeared to be the best choice. To protect the bike and the rider we needed to design a charging circuit that would charge the cells to the maximum value of 4.2V and then, before charging further, let them drop down approximately to the nominal value of 3.6V. Luckily, we found a brilliant circuit designed specifically for this use (See Figure 3). It is based around the LM3420, which is a chip that senses voltage at 4.2V and immediately opens another gate. Utilizing this, we could create a circuit that would open up a new section of circuitry at the exact point the cell reaches 4.2V. This new section would "absorb" some of the voltage and drop the level down to around 3.6V.

Also matching up with the 48V system was the motor controller and the motor. We chose to use a Curtis 1204x because of its simple design and weight efficiency. The motor was just as easy to decide upon. There are many motor manufacturers, but one stood out consecutively in every test: the Lynch Motor. The Lynch Motors are capable of providing great power with very little weight. The model we chose runs on 48V and can provide up to 9kW and weighs less than 20 lbs.

3. IMPLEMENTATION

3.1 Construction

The construction process for our prototype began with constructing numerous straw models to get ideas of different frame designs and to begin analysis of weak spots in our design. The second step then was to build a full size model to be able to see where different components would fit and to get a better idea of the feasibility of our design. We bought steel electrical conduit (EMT) and cut pieces to length. We simply pinched the ends together and then bolted the pieces together. Once we completed this model we began questioning different aspects of it and how the components would fit on. After resolving the issues we were questioning with our design, we decided to make our first prototype. For reasons such as cost and ease of welding, we chose one inch square steel tubing for the first prototype. The prototype construction began by cutting the tubes to length and setting them up by clamping them together to ensure they fit together properly. We then mig-welded the frame together and ground down some of the welds to make them look better.

There were many things learned throughout the construction process. As we worked with our frame design, we found it to be very practical for many reasons that we had not even anticipated. For instance, in the implementation of the rear suspension, we found that the placement of the shock could be very different than that of a typical bicycle. Traditional designs usually place a single shock absorber above the swing-arm and mounted to the frame. As previously mentioned, though, the problem we faced was that the point at which we were going to mount the shock to the frame was a weak point in our design. It was actually only designed to support the seat as a backrest. After much brainstorming we decided to extend the swing-arm past its pivot point and mount the shock absorber vertically under the swing arm to the low point of the pyramid on the main frame. Our suspension system now acts as a see saw with the wheel mounted at one end and the shock absorber at the other. This change gave us the strength we needed while not causing us to totally redesign our frame.

Another interesting aspect of our design is that although we made continuous additional changes to improve the design, we realized more and more that our original design was good and functional the way it was. The prototype we built out of steel will be a complete working model; however, we recommend rebuilding the frame out of aluminum, for the reasons of weight savings and overall efficiency.

3.2 Operation

As mentioned previously, we conducted extensive finite element analyzations. Working with the analysis in hand, we were able to design a frame that met our objective of having a stress safety factor of 2.0 with a 230 lbs. driver. Another criterion we judged the final product upon was the weight. We originally were given a guideline of keeping the weight of the entire bike and its components to less than 100 lbs. With careful planning we managed to keep the bike to 91 lbs. We also needed to evaluate the stopping force of the brake system that we implemented in the prototype. We conducted several days of testing on this aspect as we considered the safety of the bike to be of the utmost importance. Knowing that an average family sedan can decelerate from 60 mph to 0 mph in 80ft. to 120ft., we set our goal at 100 ft. Although we could not test the bike at speeds that great, we did however, analyze the data and extrapolate some estimates that proved that our goal had been reached.

4. SCHEDULE

Our planning and preparation was greatly affected by certain unforeseen delays. The most unfortunate delay was the failure to meet early with our sponsor, Dr. Kejha. Most of our research up until that point (mid November) was aimless research on hydrogen-powered engines, when the main focus of our project was later discovered to be the frame design and analysis.

There were other obvious shipping delays that hindered our project. Our batteries were held up in customs in Singapore for about a week, until we attained the required signatures.

Also, one major delay we encountered was learning new software programs such as AutoCAD and I-DEAS. We anticipated that in order to learn these programs, a tutorial would suffice. However, these programs (I-DEAS, especially) proved to be much more difficult than expected to learn – not only for us, but also for the people that helped to instruct us.

5. BUDGET

Components	Retail Cost	Actual Expenditures
1st Prototype Frame	$10	$100
2nd Prototype Frame	$100	$2,200
Batteries	$4,400	$0
Battery Housing	$1,800	$0
Motor	$395	$0
Generator	$395	$0
Engine	$85	$0
Disc Brakes	$230	$170

Total Prototype Cost = $2,470
Total Production Cost = $7,405

6. CONCLUSIONS

To summarize the hydrogen-electric scooter project from our group's viewpoint, we learned a lot. After months of individual research, we were able to meet with our sponsor, Dr. Joseph Kehja. He was able to provide us with additional guidance and direction towards a more specific design. From here, our group was able to learn a lot through brainstorming amongst ourselves and with our advisor, Dr. Donald Pratt. We designed a very durable and effective frame through a collaboration of some of our team member's prior knowledge of motorcycles/cars, static analyses, others' recumbent bike designs, and also trial and error.

As a group, we learned to function cooperatively by nominating a team leader who delegated tasks and assignments to the rest of the group. We learned both to accept our roles and the ability to "sell" our ideas through brainstorming at our team meetings. Our group learned quickly the importance of time management in light of our overall objective. The presentation and reports were also beneficial in providing us with experience in effectively relating our designs, ideas, calculations, etc. to both the general public and also our colleagues.

Our main objectives of minimal weight, frame durability, and efficiency of particular components were met. Overall, we were satisfied with our results and are excited to see what the next group will accomplish in the following year. This project was both an excellent learning experience and at times very fun to work on.

7. RECOMMENDATIONS FOR FUTURE WORK

Throughout this year's work on the project, many design changes were made to improve the comfort of the ride and the overall "feel" of the scooter. We were pleased with the final design and feel that we made a lot of significant improvements to the original prototype; however, we discovered through testing that there are certain aspects we may have designed differently. The first problem area we found in our design is the rear swing arm. While turning, the swing arm shows some deflection because it is not rigid enough. Although the addition of the motor mount will increase its rigidity, we can only speculate as to whether or not this will be sufficient to resolve the problem. Another solution to this problem is to redesign the swing arm, or even to implement the same design with another, more rigid material. The second area in which we see the need for improvement is the steering system. Although the design itself is strong, it became apparent through extended use and testing that there is some play in the mechanism. To resolve this problem, we recommend implementing bearings into the system, which would produce a free-moving, durable system better able to handle fatigue loading.

The remaining recommendations we have for the project all relate to the task of simply finishing the design and construction of the entire scooter. The large areas that have work to be completed are: implementation of the electrical system, reconstruction of the frame, and finally, integration of the hydrogen system. The electrical system is complete in its design, and most of the required parts have been obtained, with the exception of a generator, a controller, and a throttle. Although the batteries have been purchased, the battery packs still need to be constructed. The electrical system should be tested as a complete unit and finally assembled on the frame. The frame design, although completed, is still in need of a few minor adjustments, which have been previously discussed. Also, we constructed the prototype frame using steel, for practicality. However, we feel that once the entire design is proven as a working unit, the final product frame should be constructed from aluminum, in order to minimize the overall weight of the scooter. Our final recommendation for future work is to implement the gasoline to hydrogen fuel conversion. This will inevitably be the final leg of the design step, because it is not worth spending time on the conversion until the entire design is completed and proven to meet the desired specifications.

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Appendix A – Designs

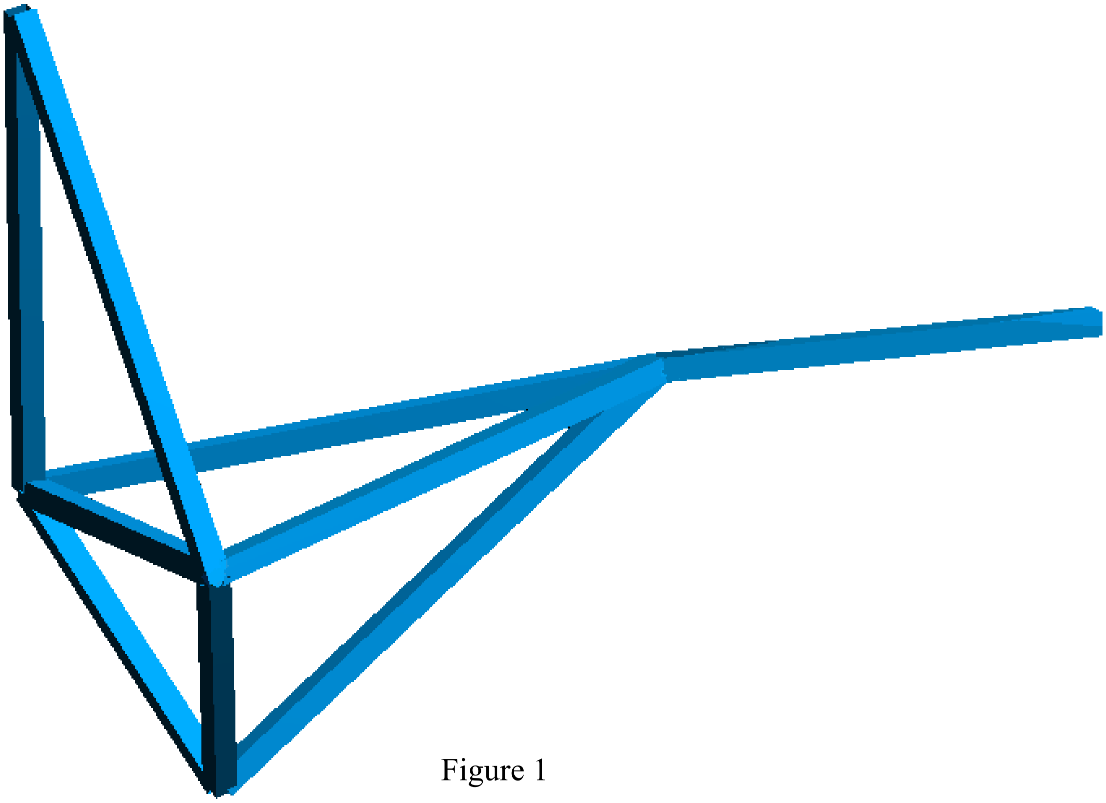

Figure 1

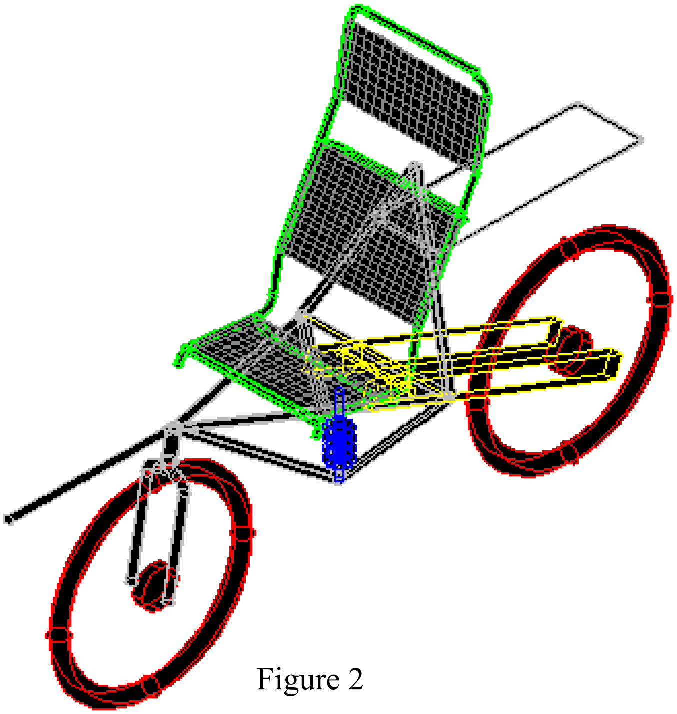

Figure 2

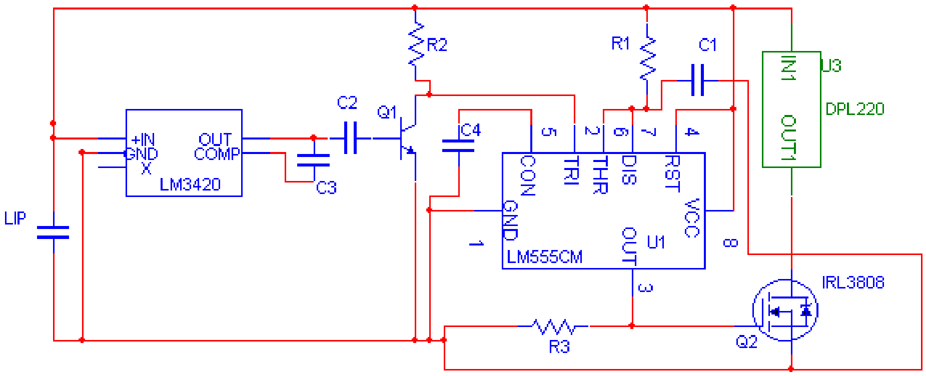

Figure 3 Li-Polymer Cell Charging Circuit
- 4.2 V Restriction -

Appendix B – Structural Analysis

The following Finite Element Analysis results were obtained with I-DEAS software. For this analysis, the weight of the scooter frame was estimated at about 100 lbs, and a 250 lb. rider was added to this weight for a total of 350 lbs. The resulting 5g load is 1750 lbs, and a 4g load is about 1400 lbs. Designing for a stress safety factor of at least 2.0, we used 1 in. diameter tubing with a wall thickness of 0.125 in. for the entire frame. Specifically, the materials tested were Magnesium ZK60A, and Aluminum 2024-T4.

Analysis	Loading (lb.)	Max. Stress (ksi)	Max. Deflection (in.)	
			Magnesium	Aluminum
Frontal Impact	1750	9.05	0.0425	0.0265
Suspension Compression Impact	1400	29.7	1.01	0.632
Rear Side Impact	1750	20.3	0.185	0.101
Mid-Frontal Side Impact	1750	9.34	0.162	0.116

Appendix C – Specifications and Gantt Chart

Engine:

Manufacturer: Honda
Configuration: Single cylinder engine, four cycle, tuned for hydrogen combustion
Bore and Stroke: NA
Displacement: 33 cc
Compression Ratio: NA
Maximum Power: 1 hp @ 7000 rpm
Maximum Torque: NA
Fuel: Hydrogen gas
Lubrication: Wet sump
Cooling: Air-cooled
Exhaust: Honda factory exhaust
Valve train: SOHC
Ignition: Solid state
Starter: Pull start

Chassis:

Frame: Magnesium tube frame
Dimensions: Length: 70’’
Wheelbase: 48’’
Seat Height: 18’’
Overall Height: 40’’
Ground Clearance: 6’’
Front Suspension: Bicycle manufactured elastomer suspension fork
Rear Suspension: Swing arm type, Coil over spring, Air/ Oil damped
Adjustable Rebound and Preload
Wheels: Front: custom-made 20” aluminum
Rear: custom made 20” aluminum
Tires: Front: 20x2.2”
Rear: 20x2.2”
Brakes: Front: Single Disc
Rear: Single Disc
Calipers: Hydraulic
Fuel Capacity: 1 gallon
Colors: Natural Steel

Performance:

Top Speed: To be determined
Acceleration: NA
Fuel Economy: NA
Turning Radius: 120’’

Weight Limit: 330 lbs (rider plus load)

Components:

Alternator: Output: 48 volts @ 6000 rpms
Weight: 20 lbs
Height: NA
Width: NA
Length: NA
Battery Pack: Weight: 22 lbs.
Height: 6’’
Width: 12’’
Length: 12’’
Max Output: 100 amps @ 48 volts
Controller: Make: Curtis
Max voltage: 72 volts
Max current: 240 amps

Cost:

Prototype: $ 2470 (est.)
Production: $ 7405 (American Currency)