Ohio Northern University Solar Powered Boat

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Abstract

The purpose of this project is to design and build a boat that is operated by a driver and powered by solar energy. The team will compete against many other universities in the Solar Splash competition. The competition is comprised of three different races and a technical report. The three different races are the slalom, the sprint, and the endurance race. The Solar Splash competition also places multiple constraints on the boats components, such as limiting the size of the boat, the size of the batteries, and the size of the solar panels. The purpose of these constraints is to give every university the same chance to succeed, even if the budgets are different. The underlying objective of this competition is to try and raise awareness for powering boats through the use of renewable energy. The competition challenges students to explore solar energy applications for marine vehicles rather than using traditional combustion engines.

Objective

The primary reason for this project is to serve as a senior design project. This is the first year Ohio Northern University has done this project. The intentions are to make it into a senior design project or a club for future years. The main goal is to design and build a boat that competes well against other universities and provide a good foundation for future students to improve on the existing design. Due to it being the first year Ohio Northern University has competed in the Solar Splash competition, everything had to be designed and built completely, which made time a critical factor. Another objective of the project is to help students learn boat design and construction and project management that will transfer into career skills.

Project Overview

The goal of this project is to promote clean energy in transportation. In order to do this, a boat solely powered by electricity captured through solar energy will be designed for competition. The proposed boat design can be found below in Fig. 1 and the actual nearly finished hull is shown in Fig. 2.

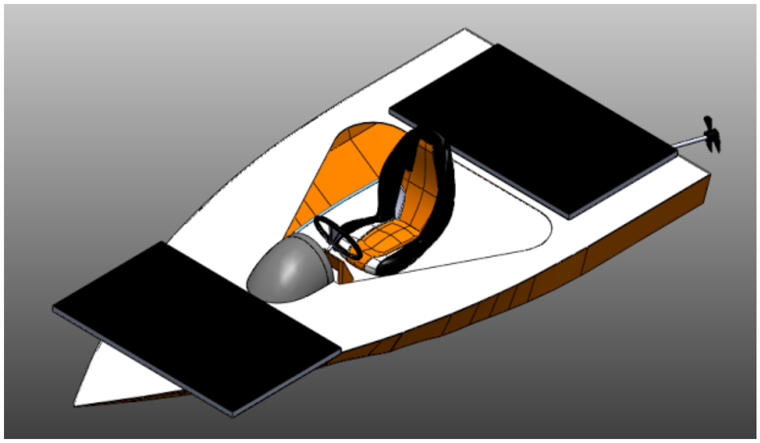

Figure 1: Model of Complete Boat

Figure 2: Actual Design

The electrical system collects solar energy from the solar panels and then stores the energy in batteries. Due to the solar panel efficiency being low, Maximum Power Point Tracking (MPPT) is used to help charge the batteries more efficiently. The batteries power the motor, which drives the propeller shaft. The motor must be able to respond to different inputs in order to have variable velocities.

The mechanical design of the boat is also crucial. Since solar panel efficiency is low, optimizing the hull design and minimizing the weight of the boat is important to conserve energy. The hull needed to be designed and modified in order to maintain buoyancy and stability. It also needs to be lightweight in order to achieve lift out of the water to minimize drag. Strength is also equally important because not only can the boat not crack or break due to forces but eliminating flexing of the material when it is in contact with the water is an essential factor in eliminating drag.

Weight distribution was also examined in order to reach maximum efficiency. Due to a large amount of weight being in the boat such as skipper, batteries, motor, solar panels, and other components, positioning these items to create proper stability is important. Minimizing weight by selecting lighter components was key in reducing drag and allowing the boat to achieve lift out of the water.

The drivetrain needed to be designed to optimize efficiency and deliver the most possible power. Again there were many choices for the design, all of which have advantages and disadvantages. In order to optimize the drivetrain limiting the amount of components was a significant factor due to energy losses that occur in each component.

The throttle control for the boat had to be easy to use. This means that the skipper needed to be able to easily maintain a constant speed throughout the entire course of a race. This is especially important for the endurance portion of the competition. Doing this helps the boat maintain a higher efficiency.

In order to control the boat, the steering system also needed to be simple and easy to use. This is important because during the slalom portion of the competition, the skipper will have to make multiple turns and will not want to fight slack in the steering, minimizing the efficiency of the boat. To do this, the travel of the propeller shaft was measured and taken into account to ensure that the desired turning radius could be met without having to use excessive force.

Design Description

Electrical System

The electrical system consists of solar panels, MPPT, batteries, motor, and motor controller. The two solar panels the team purchased are polycrystalline panels that are each rated at 240 watts. This meets the competition rule of having no more than 480 watts of energy generation.

Each solar panel has a maximum power point tracking device connected in parallel before reaching the battery cell for safety and maximum efficiency. This device can be seen below in Fig. 3.

Figure 3: Maximum Power Point Tracking Device

The competition also puts constraints on the batteries used to power the motor. The competition limits the group to two sets of 100 pounds of batteries. The source voltage for the system can also not exceed a rated value of 36 volts. The batteries that were purchased are each rated at 12 volts and each weighs approximately 31 pounds.

There are many different pieces of equipment that go into the electrical system of the boat besides just the batteries and the solar panels. Some of these include the electric motor, the motor controller, emergency stop, ignition, throttle, forward and reverse switch. The cost of these parts and their compatibility went into the decision of buying a motor kit. This decreased the cost of each individual part, which helps the project stay within the budget. Also, many of these parts are made to work with each other, which guarantees that they are compatible. The motor is a DC brushless motor, that is rated at 36 volts with 10 kW of continuous output power, and a peak output of 24 kW. The motor weighs 35 pounds with a rated efficiency of 92 percent. The motor had rotor speeds of 3700 rpm at no load. The throttle had to be changed from the original kit. The original motor kit came with a handlebar throttle, which requires the user to hold it in place for the duration of the event. This would be a problem in the endurance race for two reasons. The skipper would be tired by the end of the two hours and this would decrease performance due to inconsistent speeds, causing unnecessary acceleration and deceleration. A car's cruise control is what the group wanted to emulate so a different type of throttle was purchased. This type of throttle is a potentiometer box, which holds its position wherever it is set. This has been wired into the system replacing the old throttle.

Another requirement of the competition is the use of a deadman switch. It is required that every boat has a device that cuts power to the motor if the skipper leaves the craft. A tether switch in combination with a relay was designed to work as the dead man switch. A standard tether kill switch would not be sufficient because the maximum amperage of the switch would not be able to support the current draw during acceleration. A high amperage relay was purchased because it can support these high currents. When the tether is connected to the switch it works as a closed circuit and allows current to pass. When the tether is pulled, it opens up the switch and blocks the current flow. This current powers the relay coil, and because the relay is normally open, the relay contact is closed. If power is cut from the relay input, it will revert to its normally open state resulting in power being cut from the motor. This satisfies the requirement of the dead man switch.

A bilge pump is also required in case the boat takes on water. A manual bilge pump and bilge pump switch was purchased. These will be wired together and can be manually flipped on if it is needed. Both the dead man switch and the bilge pump are wired together and are running off of a separate 12 volt battery as shown in Fig. 4.

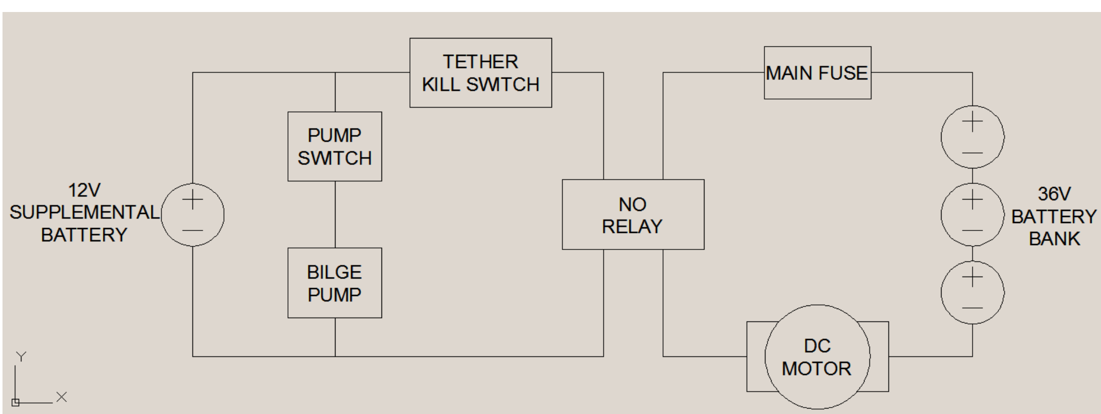

Figure 4: Safety Wiring Diagram

Hull Selection and Modifications

Due to limited time and resources, using an existing hull seemed the most reasonable. To save money a Switzer Craft boat was donated to the group. The boat was in very poor condition with numerous holes needing to be repaired and modifications such as a floor and top deck necessary. The original hull can be found in Fig. 5, below.

Figure 5: Original Boat Hull

Another issue with the boat was length and weight. The boat was eighteen feet long and originally designed for a large engine. Therefore, the boat was shortened by removing the existing transom, which was too heavy for our application and replaced with a new one constructed from ⅜” plywood. A floor was fabricated and filled with polyurethane foam to increase hull rigidity and maintain buoyancy in the event of capsizing per competition requirements. The boat with the holes patched and the floor and transom installed can be found in Fig. 6, below. The miscellaneous boards going across the top of the boat were temporarily holding the sides of the hull in position.

Figure 6: Modified Hull

The final dimensions of the boat are 15’4” long, 7’2” wide, and a maximum depth of 26”. The hull was uniquely painted, inspired by school colors and can be found in Fig. 7 below.

Figure 7: Painted Hull

The hull had a top deck installed to increase rigidity. The deck was constructed of ¼” plywood and then a cutout was made for a driver to be able to sit inside of the boat as well as the other components to be easily accessible. The model can be seen in Fig. 8 below, which shows the top deck and cutout along with the overall layout of the boat.

Figure 8: Boat with Top Deck Assembled

In order to install the drivetrain the waterline height had to be determined to ensure that only the propeller would be submerged. In order to do this the boat had to be placed in the water with an approximate equivalent weight of installed components inside of the boat. This method also helps to determine if there are any leaks in the hull that need further repairs. Due to cold temperatures most lakes and rivers were frozen so the ice had to be broken up. The boat floated well with no significant leaks and can be seen in Fig. 9 below.

Figure 9: Waterline Height Testing

This method has some error involved due to reasons such as possibly resting on an ice sheet and weight and position of components being different. However, all that was needed was a rough estimation because the drivetrain design has allowance for being positioned well above the waterline height.

Drivetrain Design

The drivetrain design that was chosen was a surface drive. A surface drive is a method of propulsion in which the propeller operates only partially submerged in the water, which reduces drag. The surface drive was selected because it can achieve a higher efficiency and higher speeds as compared to other drive systems. The surface drive that was designed is shown in Fig. 10, below.

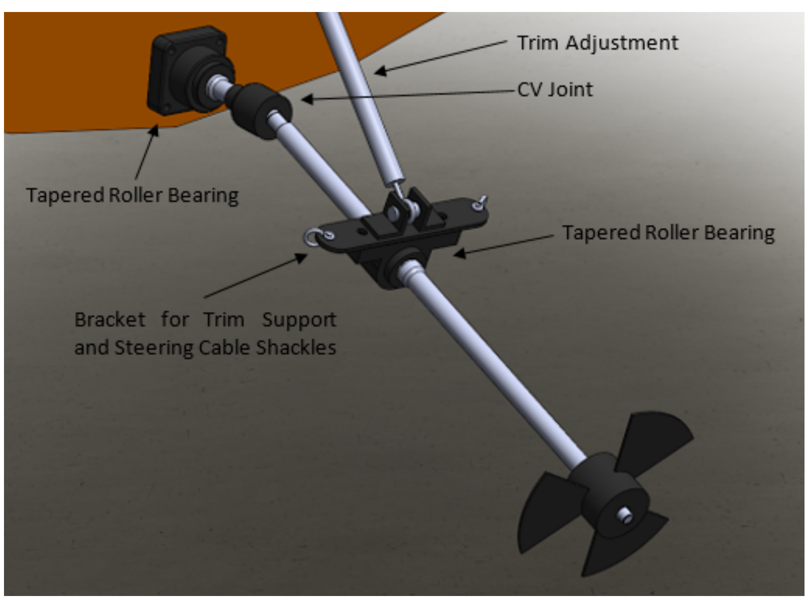

Figure 10: Drivetrain Model

As shown in the figure, the surface drive utilizes a CV joint that allows approximately 19 degrees of freedom in all directions. Two tapered roller bearings are used for support to counteract the thrust forces of the propeller. Also shown in the figure is the bracket, which the trim support is connected to as well as the two steering cables. A timing belt with a simple 1:1 gear ratio will be used to transfer power from the motor to the drive shafts. A timing belt was chosen due to its ability to sustain high RPM's, simplicity, ease of implementation, and high efficiency. Fig. 11, below, shows the assembled drivetrain mounted to boat.

Figure 11: Assembled Drivetrain

Steering Design

The steering design utilizes a mechanical cable and pulley system. This design consists of multiple pulleys that guide a steel cable along the frame of the hull, where it connects to the bracket on the propeller shaft. The steering column is composed of a steel rod, mated with 2 bearings, one mounted on the console, the other mounted at a downward angle. This allows the steering wheel to be in a comfortable position for the operator. The steering column also includes a pulley located on the steel rod between the bearings that controls the cable movement.

The steering wheel is a quick connect racing wheel. The wheel uses a sleeve that mates with the steel rod and uses a roll pin to secure the connection. The quick connect style steering wheel has a push release hub to easily connect and disconnect the steering wheel. The console design can be seen in Fig. 12 below.

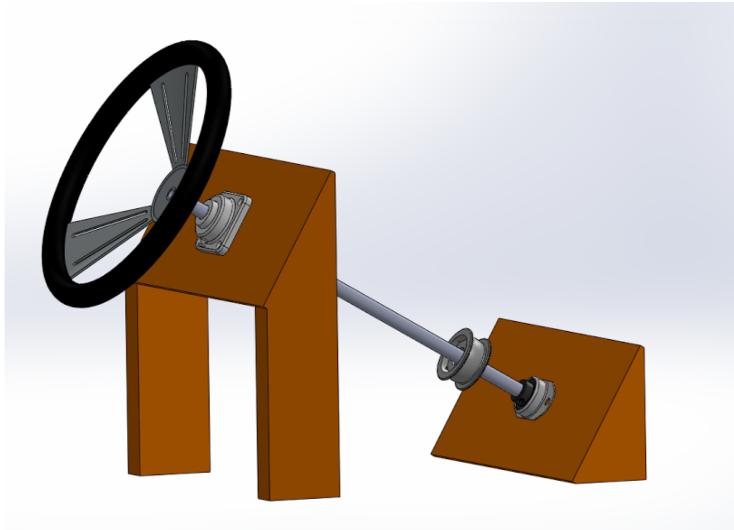

Figure 12: Steering Console and Steering Column

This design was chosen over a hydraulic steering system, based on cost and feasibility. Based upon estimated travel of the propeller shaft, a pulley diameter of two inches was chosen. The travel of the propeller shaft was found using this model. With a two-inch diameter pulley, the maximum turning angle will be achieved with approximately ¾ of a turn of the steering wheel. This results in a responsive steering system. The installed steering system is shown in Fig. 13, below.

Figure 13: Installed Steering System

Design Evaluation

In order to verify that the boat is designed and built optimally, each component must be evaluated and modified if needed to be able to perform as flawless as possible. The overall performance of the system was modeled using Engineering Equation Solver (EES) to obtain theoretical results of numerous characteristics such as velocity. There are a lot of variables and unknowns for characterizing the performance of a boat and therefore experimental testing is imperative to obtain valid results.

Mechanical Component Testing

There are numerous mechanical aspects that needed to be tested to ensure proper functionality. One of the aspects that needed testing was craft buoyancy. In order to pass the test the hull must obviously not sink but also sit a comfortable distance out of the water to insure the hull won't take on water in rough conditions. To verify that the hull displaces enough water, all of the components including the operator were placed in the hull. The hull was then placed in water to validate the buoyancy calculations. Due to the hull having a shallow-vee construction, a sufficient amount of water was displaced and the hull did not submerge below the chines, which is the maximum height the water should reach. Therefore, buoyancy of the boat is more than adequate.

Another important element that needs to be evaluated is the steering system to ensure sufficient maneuverability. In order to test the maneuverability of the craft, a slalom course much like that of the slalom course in the Solar Splash competition will be created. In order to pass the test the craft must be able to effectively maneuver the course without coming in contact with any buoys and be able to do so within a reasonable timeframe.

The Solar Splash competition specifies the method and requirements for testing stability. It is stated that 10 kg will be placed at the sheer line (outer edge at the beam) with the operator stationary in the normal operating position. The craft must not heel more than 15° with the operator remaining centered with hands and feet in normal position.

A critical function in order for the boat to plane easily and deliver the maximum possible thrust is adjusting the angle of attack of the propeller, also know as trim. In order to optimize the craft for each specific race, testing will be done to find the optimized trim for each scenario. Most likely a different trim setting will be necessary for each race. For the sprint race, the trim will be set to optimize merely top speed. For the slalom race the trim must be set to optimize maneuverability and still maintain a high speed. For the endurance race the trim must be set to optimize efficiency at a lower speed.

Numerous testing constraints have yet to be completed because the boat is still under construction. However, testing is one of the most important phases of the project and a sufficient amount of time will be dedicated to testing in order to verify and optimize the designs.

Electrical Component Testing

The electrical components must be tested before and after they are implemented on the craft to ensure that they are operating properly. The components have been tested individually, and have yet to be tested while connected on the boat. One of the electrical components that needed testing was the solar panels. The solar panels were tested in two different weather scenarios, a clear sunny sky and a cloudy sky. The output voltage was measured using a voltmeter at different times during the day in both situations. This provided an idea of how the panels will perform during the competition in June.

The motor controller was tested to ensure proper functionality. The built in voltage control capabilities of the controller was measured using the 36 volt battery bank. The device was then tested under a constant voltage and current draw for an extended period of time to make sure the controller does not exceed operating temperatures.

A very important item that needed to be evaluated thoroughly is the motor. The motor was connected to the battery bank, and the revolutions per minute was measured using a tachometer.

The dead man's switch was tested while the motor was running. The tether switch was pulled from the circuit and power was cut to the motor causing it to stop. This verifies the functionality of the switch.

Conclusion

The project is not yet complete, however all aspects are designed and currently under construction. Thus far, the project has served well for enabling the use of engineering knowledge and team skills learned through education. The project has also allowed the group to problem solve in a real world application. There are numerous aspects of the project that need to be examined all within a time and budget constraint, which helps educate the group on real world project management.