#8

Roger Williams University

SOLAR SPLASH

RWU SOLAR SPLASH

Team Members:
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Dr. Charles Thangaraj

Other Advisors:
Dr. Anthony Ruocco
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I. Executive Summary

Roger Williams University has entered the 2016 Solar Splash competition as a rookie team with a boat that is the product of two years' effort. The creation of this boat was the study of the undergraduate Senior Design class for both the 2014-2015 and the 2015-2016 school years. The main product of the 2014-2015 team was to design and build the hull of the boat with an entirely new and unique design. The current team, the 2015-2016 team worked to design the systems to power and drive the boat so that it functions efficiently. This year's team originally started out with four members, three mechanical engineers and a computer engineer. During the fall semester, the team focused on the design, purchasing, and assembly of the solar system, as well as the preliminary designs and the purchasing of materials for the rest of the electrical and driving systems for the boat. The spring semester mainly focused on the assembly and testing of these designs to ensure that the boat would be ready for the competition in June.

A complication arose in the spring which caused one mechanical engineer to leave the team, reducing it in size to a three person team. The remaining team members focused on refining the designs of the previous semester, including reducing the weight and complexity of the solar panel connections. Another focus of the semester was coming up with the different configurations of the boat for different races, including connecting a second set of batteries for the Endurance Event. The hull of the boat was repainted in order to reduce the drag it would create and a new and unique steering system was designed for precise and quick maneuverability around turns. These, along with other design refinements have improved boat handling for the competition.

The solar panel setup consists of eight 60 W panels in order to obtain the exact value of 480 W charging capability. The panels are inflexible monocrystalline panels, connected to the three Optima yellow-top batteries via Renogy charge controllers. The batteries are connected in series to a Kelly KBL motor controller which powers a Moto-energy motor directly connected to the driveshaft. The entire design was kept simple due to the fact that this is the first year of competition.

Through the process of designing and creating a fully functional solar/electric boat this team has gained new skills and appreciation for the field of engineering. Despite not having an electrical engineer as a team member, with advice from faculty we have been able to fully design and build a boat that will be very competitive in this year's Solar Splash competition.

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II. Overall Project Objectives

Because the Roger Williams Solar Splash team is a rookie team this year, the project objectives were kept simple. Primarily, the team's goal is to qualify and participate competitively in the 2016 Solar Splash competition. Along with this, the team has focused on designing with the Endurance Event as the race to focus on when making design decisions. The goal for the top speed of the boat was to hit twenty-five miles per hour with the use of only one motor. Many of the components used for this year's competition were purchased by a previous Roger Williams Solar Splash team which never made it to competition. In order to conserve money this year the team also set an objective to use as many previously purchased parts as possible in the overall design of the boat.

III. Solar System Design

For our current design, the team purchased eight 60 Watt solar panels to exactly meet the 480 Watt maximum allowance in the competition guidelines. We chose Alecko rigid monocrystalline solar panels instead of flexible cells because they perform at a higher efficiency. The solar panels are split in a 3:3:2 ratio for configuration for charging the three batteries (see Figure 1 below). Each set is wired to their own Renogy 30 amp PWM charge controller using MC4 connectors and 8-gauge wire. A 10 amp fast blow fuse inside a waterproof AGU fuse holder is connected from each of the charge controller to a 12 volt battery to protect the system in the event of excess current. The three batteries are connected in series with a 36-volt output using 4-gauge audio wire and InstallGear battery terminals. This design gives us a larger fall tolerance then a design consisting of a single charge controller. If something were to happen one of our charge controller, the whole system would not go offline, instead only a single set of the solar panels would stop charging the batteries.

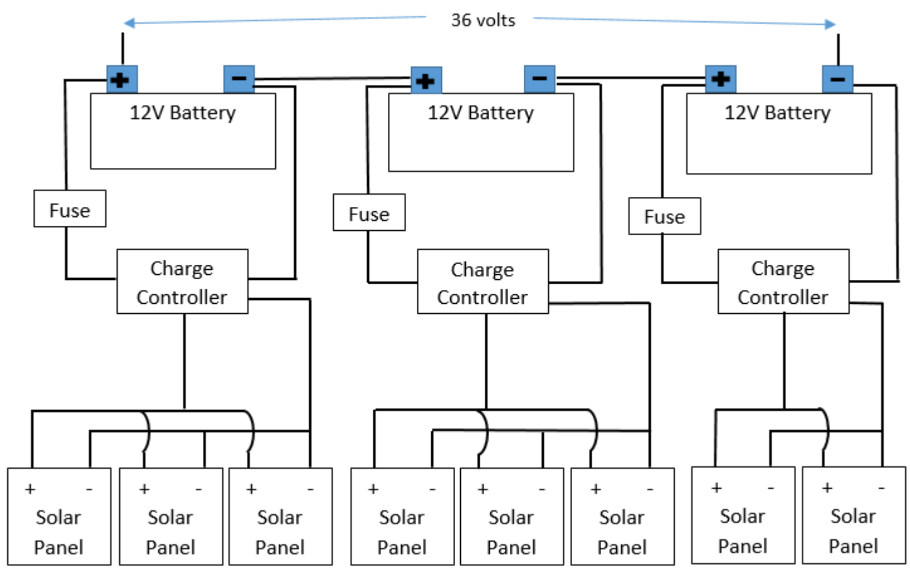

Figure 1: Diagram of the solar panel configuration and how the panels are wired to the batteries.

The batteries used are Optima Yellow Top D51R with ratings of both twelve Volts and 38 Ah which were one of the components used that had been previously purchased.

The layout of the solar panels to the boat can be seen in Figure _ below, where the 3:3:2 ratio is clearly seen. For ease of attachment and removal the panels on the sides of the boat are bolted together, then connected by U-brackets to the outrigger supports. The two panels on the back of the boat are bolted directly onto the back of the boat using L-brackets.

Figure 2: Image of the solar panel layout when mechanically fastened to the boat.

IV. Electrical System

The complete electrical system, as seen in Figure 3, is an extension of the solar power system described in the previous section.

The motor we used was a tri-phase brushless DC motor - Moto-Energy 0913. This motor was purchased by last year's team but was never tested or used. Instead of purchasing a new motor we decided to adapt the motor into our electrical system due to the fact that the motor itself offers a high efficiency (above 90%) for voltages for a wide range of voltages. This motor could prove to be advantageous over a multi-motor system in the sprint event due to its high power to weight ratio.

Three Optima Yellow Top D51R batteries were connected in series that produced a maximum overall output voltage of 36 volts. The D51Rs were chosen for the endurance and sprint events because they are deep cycle and an offer high efficiency in fast discharging applications. Each battery weighs 26 pounds, which meets the weight requirement, and has a nominal voltage of 12 volts with a capacity of 38 Ah. We also bought three Might Max batteries as a back-up set if anything happens to the D51R's. These batteries are deep cycle and offer a nominal voltage of 12 volts with a capacity of 35 Ah and weigh 8.38 pounds each.

The onboard motor controller used was a Kelly KBL72401E controller was used to connect the batteries and motor, provide a DC voltage boost, and handle inputs from the skipper. The skipper will use a Curtis ET-126 throttle to control the rotations per minute of the motor shaft. The Curtis throttle is powered my running a piece of 16-gauge wire from one of the D51R's. The input voltage of the throttle is 24 volts and outputs 0 to 5 volts that goes to charge controller where it then, using Hall Effect sensors, controls the speed of the motor. The throttle included a spring return, which will reduce the effects of accidental movements.

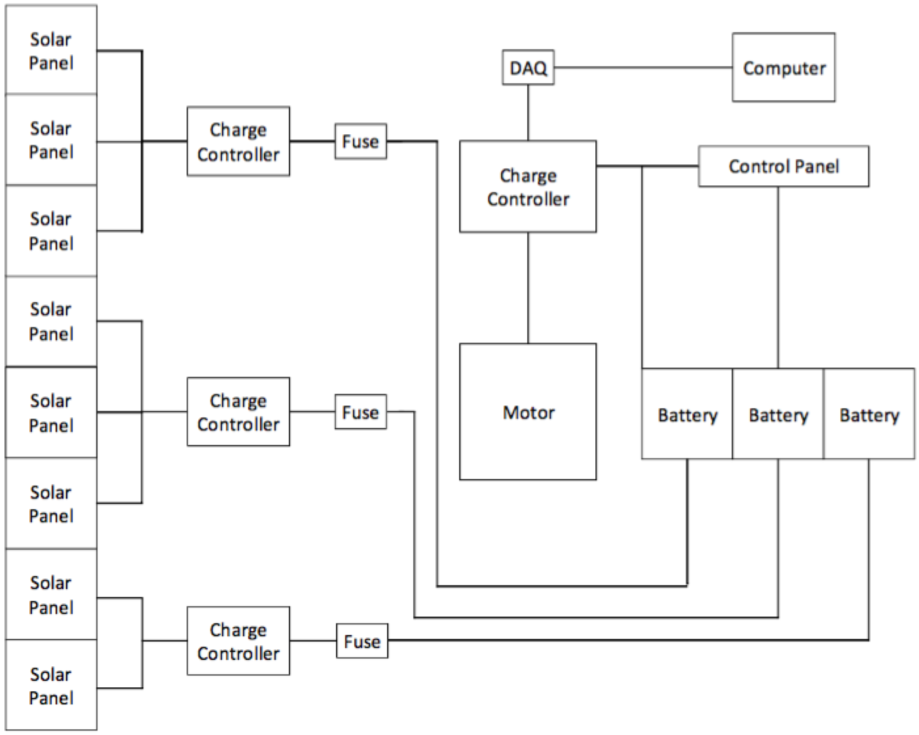

Figure 3: General schematic of the electrical system.

For high current rails between the motor and batteries, 4 gauge Class K welding wire was used. The wire was sized based on the maximum steady state current the Kelly motor controller could provide to the motor, 160 Amps. For the other wire connections 16 and 18 gauge was used. The control panel of the boat included a dead-man's switch, reverse switch, and a main power switch.

V. Power Electronics System

The design of the power electronics system was centered on the use of a Kelly KBL72401E motor controller. The reason for using this is that it is easy to use and program for a rookie team, as well as offers an efficiency of 99% and is rated for being able to use voltage loads that are well beyond what the competition calls for. The reason that the controller can obtain such high efficiencies is that it implicates fast switching power MOSFET and pulse width modulation (PWM). There is only one drawback of the system, however, and that is the noise that the controller emits from the power MOSFETS switch, which may start to effect the skipper after two hours on the endurance course, but does not affect the overall mechanical performance. This system is fully functional, but is open to possible future work before the competition with changing the programming configuration of the controller, possibly with a different program for each type of race.

The Kelly controller is connected to the batteries via a main contactor and a rated fuse. The contactor came with the Kelly controller and acts as a switch that closes the circuit when the proper voltage is applied across it. This then ruins current through a low power rail, which the skipper can disconnect through two different means. First is a toggle switch, used as a main power switch the switch must be flipped for the power to flow. The second possible disconnect point is the dead-man's-switch. A piece of this switch is attached to the skipper so that if they go overboard the circuit is disconnected and the power stops. In order to shield the skipper form the current of the circuit a rated diode is placed in parallel with the switches to draw any reverse current away from the switches when the motor is slowed.

VI. Hull Design

The three designs that were heavily considered were a V-hull, catamaran, and trimaran. It was decided that the V-hull would be the best option because it would be easy to manufacture and would offer a design that could plane, and also not do poorly in the endurance race. The initial design was a simple, essentially D shaped design with a pointed bow that was 8ft long and had a 3ft beam. As the design moved forward and started to get a rough sketch for the solar panels and the drive train it was realized that we were going to need more surface area than the original design would give us. In order to give more surface area we extended the boat by four feet so that the entire front of the boat could be used to hold the solar panels. Another reason for extending the boat is so that we could have more room to hold the batteries and other accessories and be able to have a good weight distribution. A few minor changes were made after this, including how the bow was shaped. Instead of a very sharp point, the design was moved to a more rounded tip and a smoother slope at the bow. A requirement by the competition is that the boat must be able to float if it completely filled with water. After a few tests using SolidWorks and Excel to help with buoyancy calculations it was determined that the design would sink with a full load of water in it. In order to compensate for the low buoyancy the idea was to add air bags to the inside of the boat. The air bags would be lightweight so they wouldn't affect stability and would provide the extra buoyancy.

The next step in our design process was to create a physical model and space out how much room we would need to fit all of the components and the skipper inside of the boat. After spacing out the amount of space for the drivetrain, skipper, controls, and batteries it was shown that there was less room than anticipated for the solar panels. It was determined that the design would need at least $36ft^2$ to fit the panels. In order to give that space the length of the boat was extended to 16 feet and reduced the width to 2.5 feet.

While contacting companies to see if they would assist, one company, Aquidneck Custom Composites, suggested the team contact a naval architect (David Walworth) that they often work with. During the Skype conversation they had with him, he pointed out that a trimaran would be the better option because they have very low drag and are very stable. Another draw to using a trimaran is that there would be a very large surface area to work with over the three hulls. This gives an optimal workspace to mount the solar panels in any configuration that we need. Over the following few weeks, the team worked closely with David to develop a design that would work the best. Figure 4 shows the initial design that was in conjunction with Walworth Designs. When the team brought this design to ACC (Aquidneck Custom Composites), the owner of the shop said that it might be a bit too difficult to build. The design was then made with hull shape more rounded in the aft section, as well as rid of the shaft trunk. With both of those changes made, the team was ready to start building the hull.

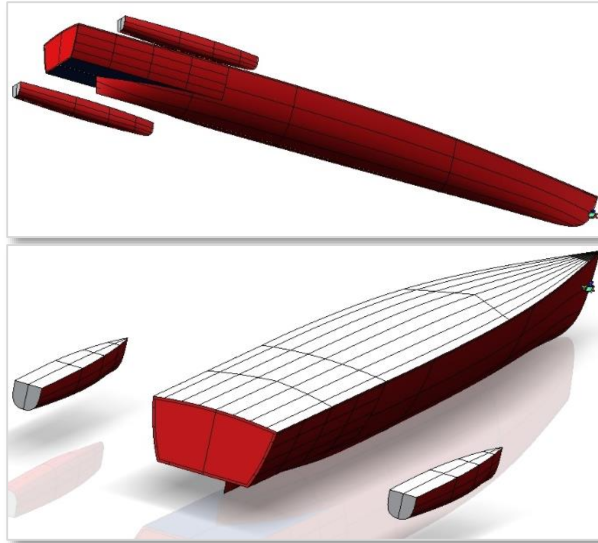

Figure 4: Preliminary design

The fabrication of the hull took much longer than anticipated. It started by creating a spine to attach all of the stations to. With the stations attached and plumb, team members started to cut the foam core into 2" and 1" strips. These strips were screwed onto the stations to make the base shape of out hull. The 2" pieces were used when the curvature of the boat was minimal. The 1" strips were used once the gunnel started its curve to the keel. With all of the foam attached and epoxied together, the foam was sanded to fair it. Two layers of 6oz fiberglass were epoxied to the outside and inside of the hull. The outside of the hull was faired with red balloons and sanded. The boat was then taken off of the mold and bulkheads were built to add stiffness and ensure the buoyancy requirement.

Figure 5: Bulkheads being installed

Figure 6: Laying down the spine for the mold

With all the bulkheads installed, the team then epoxied the deck on as well as the amas to the carbon tubes. The next step was to use Awl-Fair to make the tape joints seamless. From there, the boat was primed and finish painted.

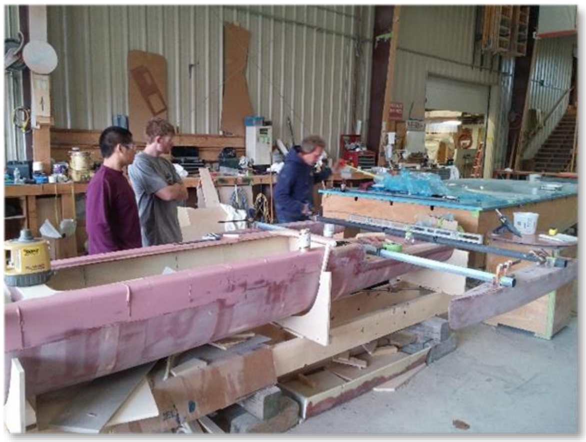

Figure 7: Aligning the amas

Figure 8: Attaching the foam core to the stations

Figure 9: Priming complete

Figure 10: Priming the hull

Once the assembly and painting were complete, the design of the electrical components and their placement in the boat was able to move forward.

VII. Drive Train and Steering

The rudder for our boat is made from a composite material and was built by the International Yacht Restoration School (IYRS) in Bristol, RI. The rudder consists of a solid 3/4th inch steel shaft with metal flanges that are incased within the material for support. Additionally, the rudder is primed and painted with the same paint used on the hull of the boat. To steer the rudder, we experimented with a few different systems, but in the end, decided to electrically turn the rudder as opposed to a manual pulley design. We mounted a Nextrox 12V 15RPM Electric DC Motor to the shaft. The motor and rudder were connected with a heavy duty variable size flexible shaft coupling from Mc Master-Carr, because the shaft of the motor and rudder were different sizes. We designed a waterproof housing out of PVC pipe and machined ABS plastic to fit around the shaft and motor. Finally, we wired the rudder motor up though the hull of the boat in front of the skipper and connected it to a reversible polarity toggle switch to control the rudder movements.

VIII. Data Acquisition and/or Communications

The Kelly Controls motor controller is capable of monitoring all data form the motor such as its temperature and speed in real time. However, as of right now the skipper will not be receiving any of this data, the motor controller itself will cut the power if the temperature exceeds a designated value (default is 90°F). The skipper will have a small voltmeter display of overall system battery voltage, in order to be able to monitor its level. If the voltage drops below 25 V the main contactor switch will open, disconnecting the circuit and all power to the motor, so it is important to monitor this level. The skipper will also be in constant two-way radio contact with a team member on shore in case any problems arise.

IX. Project Management

A. Team members and leadership roles:

Kristen Neff – Team Captain – Mechanical Engineering, Class of 2016
Kristen took on important administrative matters and worked alongside Dr. Thangaraj in creating milestones for the project. She was the team leader and decision maker of the group.

Darren McCall – Mechanical Engineering, Class of 2016
Darren came up with the solar panel array and was in charge of the steering components of the boat. He had a good technical background, which helped him design the best possible solar panel array for the boat.

Daniel Wisniewski – Computer Engineering, Class of 2016
Daniel worked alongside Kristen in the wiring of the electrical components of the boat. He designed and fabricated a control panel used by the skipper of the boat that included the dead-man's-switch, power, reverse switch, and throttle.

Rei Medina –Mechanical Engineering, Class of 2016

Dr. Charles Thangaraj – Team Advisor – Associate Professor of Electrical Engineering
Dr. Thangaraj overlooked the project and offered helpful advice from his electrical engineering background

B. Project Planning and Schedule

At the start of the year the team compiled a list of milestones that it would want to accomplish by certain dates. With the help from the team's advisor, an Excel spreadsheet was made that included a "project tracker" which described the task, the due date, the date completed, and what team member was in charge of the task. Since there were four members in the group, teams of two were formed in order to accomplish more of the tasks at hand. Difficulties and delays came with the larger parts of the project, which caused the need for more time for testing and evaluation.

C. Financial and Fundraising

Roger Williams University allocated a budget of $3,000, which allowed the team to get most of the necessary materials that was needed for the boat. The team kept track of its spending in an excel budget list spreadsheet.

The team sought potential fundraising from local boat yards. Two companies that helped the team with most difficult problems were Jamestown Distributors and I.Y.R.S (International Yacht Restoration School) both of Bristol, RI. There was also money allocated from one of Roger Williams University' chapters; the Provost Fund. An application was sent for a $1,500 contribution that dealt with looking for potential travel money. The Provost fund paid for the team's hotel in Dayton, Ohio as well as travel expenses.

D. Strategy for team continuity and sustainability

The team, along with its advisor, held weekly meetings varying in length of time depending on what was to be accomplished. Team members had constant communication with one another through text and email, along with attending the same classes. Team members would also meet when able to work on the boat in pairs in order to build each of the systems of the boat.

E. Discussion and Self-Evaluation

The main challenge faced by this year's team was the small team size, made smaller when one team member, Rei Medina, dropped out, leaving only three members remaining. This required the remaining members to focus their work much more upon their designated tasks, because there was more weight on their shoulders. Throughout the year it was learned that the key to successful team management was to divide each system into smaller tasks that could be accomplished by only one or two people, which allowed each person to work individually on their own time, rather than trying to force everyone's schedules to coincide on a daily basis. By setting goals and dividing up the work week by week even a team of three people was able to build a competitive, functioning boat. In future years other teams can build off of our work and make the boat more efficient, especially the weight of the boat and its components, such as the solar panels.

X. Conclusions and Recommendations

For future Roger Williams' teams there are a few recommendations that could be made to change the design of the boat. First of all, the steering is not self-centering; the skipper does have to steer back to center. Also, several teams have a multiple-motor system for the Sprint Course, so future teams may look into that.

Due to the fact that we are the first team to go to competition, we are not yet entirely sure of how our boat will measure in competition. Once we compete in June we will have a better idea of what advice to leave behind.

XI. References

[1] Renogy 30amp PWM Charge controllers
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[2] Podoy GMA 10amp Fuse
http://www.amazon.com/PODOY-Qty-Fast-Blow-GMA10A-GMA10/dp/B004HLYUE0
[3] 4 gauge Red and Black Audio Cable
http://www.amazon.com/Gauge-BLACK-Audio-Power-Ground/dp/B00L9CB6WE
[4] Islandoffer MC4 Cable Connectors
http://www.amazon.com/Islandoffer-Pairs-Female-Solar-Connectors/dp/B00A8TRKJW
[5] Installgear Battery terminal Clamps
http://www.amazon.com/InstallGear-Positive-Negative-Battery-Terminal/dp/B00NQ7U982/ref=sr_1_3?s=automotive&ie=UTF8&qid=1462821681&sr=1-3&keywords=Battery+terminal+Clamps
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http://www.amazon.com/ML35-12-STORAGE-BATTERY-Battery-product/dp/B00K8E4LR6/ref=sr_1_6_s_it?s=hpc&ie=UTF8&qid=1462821713&sr=1-6&keywords=Mighty+Max+12v+Deep+Cycle+Batterys
[7] Aleko 60Watt Monocrystalline Solar Panel
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[9] Nextrox mini gear box motor
http://www.amazon.com/dp/B00B1KXV3Q/ref=twister_B00Y7Z2SA4?_encoding=UTF8&psc=1
[10] IMC audio AUG inline fuse holder
http://www.amazon.com/Holder-Fuseholder-IMC-Audio-Inline/dp/B015AJQIWO/ref=sr_1_fkmr1_1?s=hi&ie=UTF8&qid=1462821846&sr=1-1-fkmr1&keywords=IMC+audio+AUG+inline+fuse+holder
[11] 8 gauge Wire
http://www.homedepot.com/p/Southwire-By-the-Foot-6-Black-Stranded-CU-THHN-Wire-20493399/204632784
[12] PVC Pipe
http://www.homedepot.com/p/VPC-3-in-x-2-ft-PVC-Sch-40-Pipe-2203/205706641
[13] Wind Shield
http://www.ebay.com/sch/i.html?_odkw=windshield&_osacat=0&ssPageName=GSTL&_from=R40&_trksid=p2045573.m570.l1313.TR0.TRC0.H0.Xwindshield++moped.TRS0&_nkw=windshield++moped&_sacat=0
[14] Shaft Coupling
http://www.mcmaster.com/#standard-shaft-couplings/=12c7j95
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[18] Switch
http://www.amazon.com/HOTSYSTEM-Aircraft-Carbon-Automotive-Illuminated/dp/B0061GQUS8/ref=sr_1_13?ie=UTF8&qid=1462822378&sr=8-13&keywords=on+off+switch
[19] Paint
http://www.jamestowndistributors.com/userportal/show_product.do?pid=1438
[20] Paint rollers
http://www.acehardware.com/product/index.jsp?productId=34220626
[21] Sand paper
http://www.acehardware.com/search/index.jsp?kwCatId=&kw=sandpaper&origkw=sand+paper&f=Taxonomy/ACE/19541496&sr=1
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http://www.homedepot.com/s/bolts?NCNI-5
[23] ABS Plastic
http://www.mcmaster.com/#abs-plastic/=12c7jhm

XII. Appendices

Appendix A: Battery Documentation

Battery Model: D51
Part Number: 8071-167
Nominal Voltage: 12 volts
NSN: 6140 01 523 6288
Description: High power, dual purpose engine start and deep cycle, sealed lead acid battery

Battery Model: D51R
Part Number: 8073-167
Nominal Voltage: 12 volts
NSN: Number applied for, product currently available **Description:** High power, dual purpose engine start and deep cycle, sealed lead acid battery

Physical Characteristics:

Plate Design: High purity lead-tin alloy. Wound cell configuration utilizing proprietary *SPIRALCELL*® technology.

Electrolyte: Sulfuric acid, H_2SO_4
Case: Polypropylene
Color: Case: Light Gray
Cover: "OPTIMA" Yellow
Group Size: BCI: 51

	Standard	Metric
Length:	9.272"	235.51 mm
Width:	5.024"	127.61 mm
Height:	8.885"	225.68 mm (Height at the top of terminals)
Weight:	26.0 lb	11.8 kg

Terminal Configuration: SAE / BCI automotive.

Performance Data:

Open Circuit Voltage (Fully charged): 13.1 volts
Internal Resistance (Fully charged): .0046 ohms
Capacity: 38 Ah (C/20)
Reserve Capacity: BCI: 66 minutes
(25 amp discharge, 80°F (26.7°C), to 10.5 volts cut-off)

Power:

CCA (BCI 0°F): 450 amps
MCA (BCI 32°F): 575 amps

[redacted]

The following charging methods are recommended to ensure a long battery life: (Always use a voltage regulated charger with voltage limits set as described below.)

Model: D51 and D51R
These batteries are designed for starting and deep cycle applications and for use in vehicles with large accessory loads.

Recommended Charging Information:

Alternator:	13.65 to 15.0 volts
Battery Charger (Constant Voltage):	13.8 to 15.0 volts; 10 amps maximum; 6-12 hours approximate
Float Charge:	13.2 to 13.8 volts; 1 amp maximum; (indefinite time at lower voltages)
Rapid Recharge: (Constant voltage charger)	Maximum voltage 15.6 volts. No current limit as long as battery temperature remains below 125°F (51.7°C). Charge until current drops below 1 amp.
Cyclic or Series String Applications:	14.7 volts. No current limit as long as battery temperature remains below 125°F (51.7°C). When current falls below 1 amp, finish with 2 amp constant current for 1 hour. **All limits must be strictly adhered to.**

Recharge Time: (example assuming 100% discharge – 10.5 volts)

Current	Approximate time to 90% charge
100 amps	25 minutes
50 amps	65 minutes
25 amps	130 minutes

Recharge time will vary according to temperature and charger characteristics. When using Constant Voltage chargers, amperage will taper down as the battery becomes recharged. When amperage drops below 1 amp, the battery will be close to a full state of charge.

(All charge recommendations assume an average room temperature of 77°F (25°C).

Always wear safety glasses when working with batteries.

Always use a voltage regulated battery charger with limits set to the above ratings. Overcharging can cause the safety valves to open and battery gases to escape, causing premature end of life. These gases are flammable! You cannot replace water in sealed batteries that have been overcharged. Any battery that becomes very hot while charging should be disconnected immediately.

Not fully charging a battery can result in poor performance and a reduction in capacity.

Shipping and Transportation Information:

OPTIMA batteries can be shipped by AIR. The battery is nonspillable and is tested according to ICAO Technical Instructions DOC. 9284-AN/905 to meet the requirements of Packing Instructions No. 806 and is classified as non-regulated by IATA Special Provision A-48 and A-67 for UN2800. Terminals must be protected from short circuit.

BCI = Battery Council International

OPTIMA Batteries
Product Specifications: Model D51 and d51R
December 2008

Appendix B: Flotation Calculations

This appendix contains the results from performing buoyancy calculations of the hull. These calculations were performed by finding the volume of each foam core component as well as the volume of every watertight compartment. This volume multiplied by the density of water gives you the buoyant force when the component is fully submerged in water. The total volume of our boat is $0.712m^2$, which provides 712kg (1569lbs) of buoyant force. This proves that our boat will still float even after being submerged because the boat and components weigh less than 350lbs. Since our middle compartment has a hatch, and thus the chance of leaking, we also calculated the buoyant force if that compartment had been compromised. In this case, the buoyant force is still 333kg (734lbs) which again, is well above the weight of our boat.

Buoyancy Calculations		
Section	**Volume (cm^3)**	**Bouyancy (kg)**
Main Hull Body	89487.7	89.49
Bow Cone	5323.1	5.32
Main Deck	28801.9	28.80
Rear Deck	9840.3	9.84
Forward WTB	30787.2	30.79
Rear WTB	127985.5	127.99
Middle Compartment	378365.0	378.37
Starboard Ama	20706.5	20.71
Port Ama	20706.5	20.71
Total	712003.7	**712.00**
With Engine Compartment Comprimised		**333.64**

Figure 11: Buoyancy Calculations (WTB Watertight bulkhead)

Appendix C: Proof of Insurance

ACORD® **CERTIFICATE OF LIABILITY INSURANCE**

DATE (MM/DD/YYYY): 7/1/2015

THIS CERTIFICATE IS ISSUED AS A MATTER OF INFORMATION ONLY AND CONFERS NO RIGHTS UPON THE CERTIFICATE HOLDER. THIS CERTIFICATE DOES NOT AFFIRMATIVELY OR NEGATIVELY AMEND, EXTEND OR ALTER THE COVERAGE AFFORDED BY THE POLICIES BELOW. THIS CERTIFICATE OF INSURANCE DOES NOT CONSTITUTE A CONTRACT BETWEEN THE ISSUING INSURER(S), AUTHORIZED REPRESENTATIVE OR PRODUCER, AND THE CERTIFICATE HOLDER.

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	INSURER(S) AFFORDING COVERAGE — NAIC #
	INSURER A: United Educators Insurance
INSURED Roger Williams University One Old Ferry Road Bristol RI 02809	INSURER B: Nationwide
	INSURER C: Beacon Mutual Insurance Company
	INSURER D: American Guarantee & Liability Ins
	INSURER E:
	INSURER F:

COVERAGES **CERTIFICATE NUMBER:** CL157202211 **REVISION NUMBER:**

THIS IS TO CERTIFY THAT THE POLICIES OF INSURANCE LISTED BELOW HAVE BEEN ISSUED TO THE INSURED NAMED ABOVE FOR THE POLICY PERIOD INDICATED. NOTWITHSTANDING ANY REQUIREMENT, TERM OR CONDITION OF ANY CONTRACT OR OTHER DOCUMENT WITH RESPECT TO WHICH THIS CERTIFICATE MAY BE ISSUED OR MAY PERTAIN, THE INSURANCE AFFORDED BY THE POLICIES DESCRIBED HEREIN IS SUBJECT TO ALL THE TERMS, EXCLUSIONS AND CONDITIONS OF SUCH POLICIES. LIMITS SHOWN MAY HAVE BEEN REDUCED BY PAID CLAIMS.

INSR LTR	TYPE OF INSURANCE	ADDL INSD	SUBR WVD	POLICY NUMBER	POLICY EFF (MM/DD/YYYY)	POLICY EXP (MM/DD/YYYY)	LIMITS	
A	X COMMERCIAL GENERAL LIABILITY CLAIMS-MADE [X] OCCUR GEN'L AGGREGATE LIMIT APPLIES PER: [X] POLICY [ ] PRO-JECT [ ] LOC OTHER:			CGL201500237700	7/1/2015	6/1/2016	EACH OCCURRENCE	$ 1,000,000
							DAMAGE TO RENTED PREMISES (Ea occurrence)	$ 1,000,000
							MED EXP (Any one person)	$ 5,000
							PERSONAL & ADV INJURY	$ Incl.
							GENERAL AGGREGATE	$ 3,000,000
							PRODUCTS - COMP/OP AGG	$ Incl.
								$
B	AUTOMOBILE LIABILITY X ANY AUTO ALL OWNED AUTOS [ ] SCHEDULED AUTOS X HIRED AUTOS [ ] NON-OWNED AUTOS			BA00000013210W	7/1/2015	6/1/2016	COMBINED SINGLE LIMIT (Ea accident)	$ 1,000,000
							BODILY INJURY (Per person)	$
							BODILY INJURY (Per accident)	$
							PROPERTY DAMAGE (Per accident)	$
								$
A	UMBRELLA LIAB [X] OCCUR X EXCESS LIAB [ ] CLAIMS-MADE DED RETENTION $			GLX201500237700	7/1/2015	6/1/2016	EACH OCCURRENCE	$ 25,000,000
							AGGREGATE	$ 25,000,000
								$
C	WORKERS COMPENSATION AND EMPLOYERS' LIABILITY Y/N ANY PROPRIETOR/PARTNER/EXECUTIVE OFFICER/MEMBER EXCLUDED? (Mandatory in NH) [ ] N/A If yes, describe under DESCRIPTION OF OPERATIONS below			24569	7/1/2015	7/1/2016	X PER STATUTE OTH-ER	
							E.L. EACH ACCIDENT	$ 500,000
							E.L. DISEASE - EA EMPLOYEE	$ 500,000
							E.L. DISEASE - POLICY LIMIT	$ 500,000
D	All Risk Property (RCV) incl Leased Equipment			ERP 0179399-00	7/1/2015	6/1/2016	Blanket Limit	500,000,000

DESCRIPTION OF OPERATIONS / LOCATIONS / VEHICLES (ACORD 101, Additional Remarks Schedule, may be attached if more space is required)

Issued as Evidence of Insurance.

CERTIFICATE HOLDER	CANCELLATION
EVIDENCE OF COVERAGE	SHOULD ANY OF THE ABOVE DESCRIBED POLICIES BE CANCELLED BEFORE THE EXPIRATION DATE THEREOF, NOTICE WILL BE DELIVERED IN ACCORDANCE WITH THE POLICY PROVISIONS.
	AUTHORIZED REPRESENTATIVE Beverly Costello/JJR Beverly C. Costello

ACORD 25 (2014/01) The ACORD name and logo are registered marks of ACORD
INS025 (201401)

Appendix D: Team Roster

2015-2016 Team Members:
Kristen Neff: Undergraduate Mechanical Engineer, Senior
Email: kneff952@g.rwu.edu
Darren McCall: Undergraduate Mechanical Engineer, Senior
Email: dmccall442@g.rwu.edu
Daniel Wisniewski: Undergraduate Computer Engineer, Senior
Email: dwisniewski660@g.rwu.edu

2015-2016 Team Faculty Advisor:
Dr. Charles Thangaraj: Assistant Professor of Engineering
Email: cthangaraj@rwu.edu

Former 2015-2016 Team Member:
Rei Medina: Undergraduate Mechanical Engineer, Senior

Honorable mention to the 2014-2015 Team Members:
Connor Adams: Undergraduate Mechanical Engineer, Senior
Andrew Carlson: Undergraduate Mechanical Engineer, Senior
Jared Delfin: Undergraduate Mechanical Engineer, Senior
Nicholas Benoit: Undergraduate Electrical Engineer, Senior
Abdulrahim Hasan: Undergraduate Electrical Engineer, Senior

2014-2015 Team Faculty Advisors:
Administrative Advisor: Dr. Anthony Ruocco
Technical Advisor: Dr. Benjamin McPheron

Appendix E: The G-code used to create the steering mechanism

G-code for the base mount of steering assembly

```
(propeller-base-mount-Groove)
N000 G20 M09
N010 G90
N020 M48
N030 F2 S1000 M04
N035 G01 Z.1
N040 G01 Z-0.375
N050 G01 X0.0 Y0.0
N060 G01 X1.25 Y0.0
N070 G02 X1.25 Y0.0 I-1.25 J0.0
N040 G01 Z-0.75
N070 G02 X1.25 Y0.0 I-1.25 J0.0
N080 F10
N090 G01 x0.0 Y0.0 Z0.1
N100 G01 X1.67
N105 F2
N110 G01 Z-0.375
N120 G01 X1.67 Y0.0
N130 G02 X1.67 Y0.0 I-1.67 J0.0
N140 G01 X1.590 Y0.0
N150 G02 X1.590 Y0.0 I-1.590 J0.0
N160 F10
N170 G01 Z.1
N180 G01 x0.0 Y0.0 Z0.1
N190 M2
```

G-code for the motor mount of steering assembly

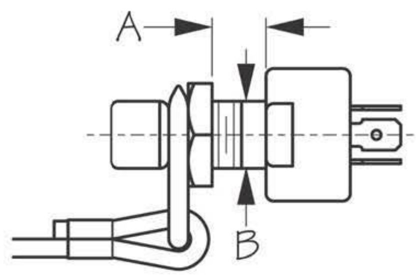
```
(propeller-motor-mount-Groove)
N000 G20 M09
N010 G90
N020 M48
N030 F2 S1000 M04
N035 G01 Z.1
NO40 G01 Z-.7
N050 G01 X0.0 Y.2953
N060 G01 X.545 Y0.0
N070 G02 X.545 Y0.0 I-.545 J0.0
N075 F10
N080 G01 Z.1
N090 G01 X0.0 Y0.0 Z0.1
N100 G01 X1.590 Y0.0
N105 F2
N110 G01 z-.7
N120 G02 X1.590 Y0.0 I-1.590 J0.0
N130 F10
```

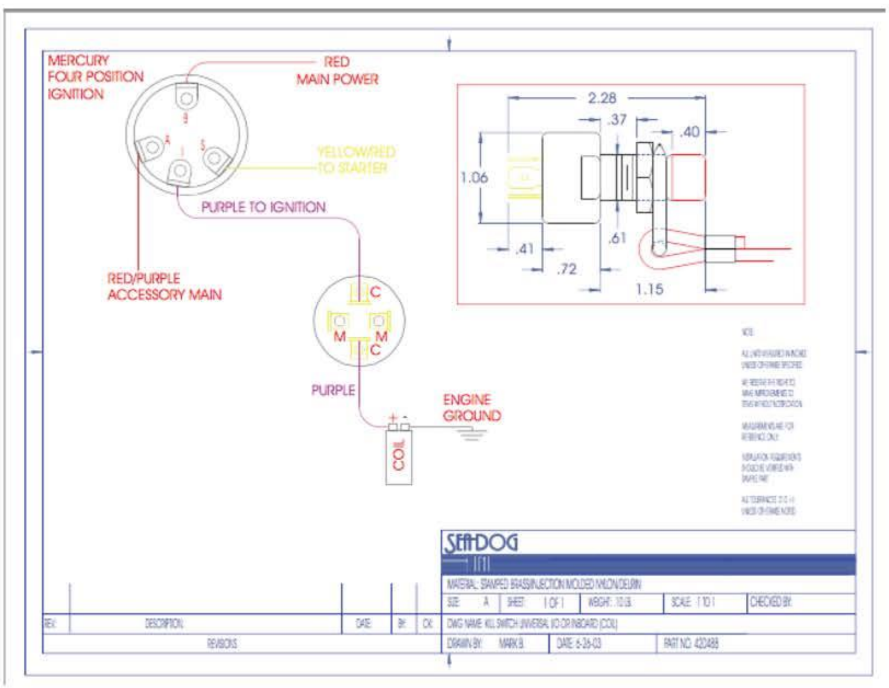
```
N140 G01 Z.1
N150 G01 x0.0 Y0.0 Z0.1
N160 M2
```

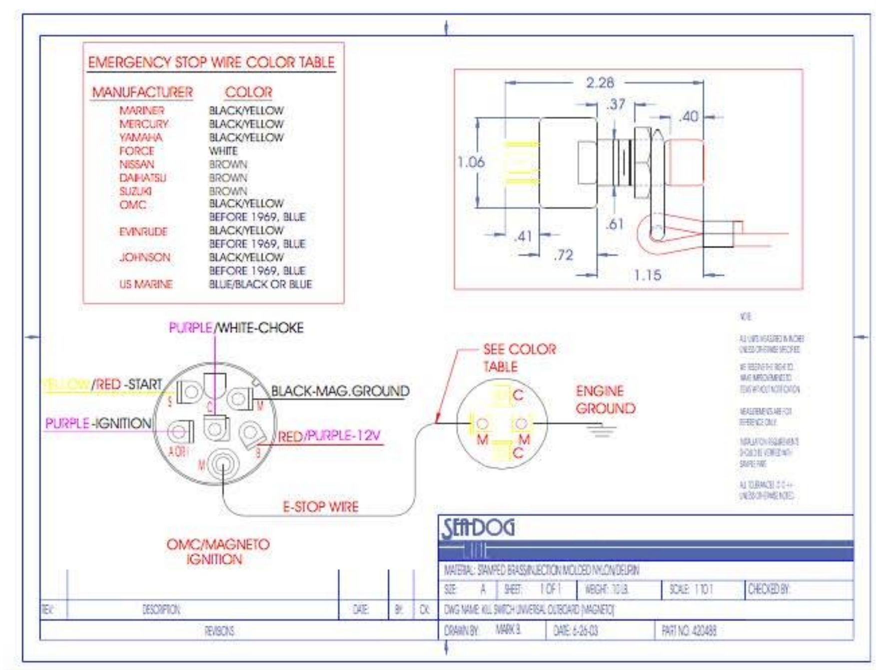
Appendix F: Specification Sheets

Sea-Dog Universal Ignition Kill Switch

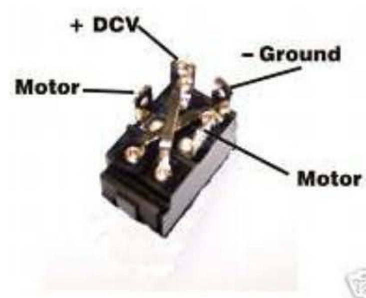
Print






EMERGENCY STOP WIRE COLOR TABLE
MANUFACTURER COLOR
MARINER BLACK/YELLOW
MERCURY BLACK/YELLOW
YAMAHA BLACK/YELLOW
FORCE WHITE
NISSAN BROWN
DAIHATSU BROWN
SUZUKI BROWN
OMC BLACK/YELLOW BEFORE 1969, BLUE
EVINRUDE BLACK/YELLOW BEFORE 1969, BLUE
JOHNSON BLACK/YELLOW BEFORE 1969, BLUE
US MARINE BLUE/BLACK OR BLUE
2.28
.37
.40
1.06
.61
.41
.72
1.15
PURPLE/WHITE-CHOKE
YELLOW/RED -START
BLACK-MAG.GROUND
PURPLE -IGNITION
RED/PURPLE-12V
E-STOP WIRE
OMC/MAGNETO IGNITION
SEE COLOR TABLE
ENGINE GROUND
SEADOG
MATERIAL: STAMPED BRASS/INJECTION MOLDED NYLON/DELRIN
SIZE: A
SHEET: 1 OF 1
SCALE: 1 TO 1
CHECKED BY:
DWG NAME: KILL SWITCH UNIVERSAL OUTBOARD (MAGNETO)
DRAWN BY: MARK B.
DATE: 6-26-03
PART NO. 420488
REV.
DESCRIPTION
DATE
BY:
CK:
REVISIONS

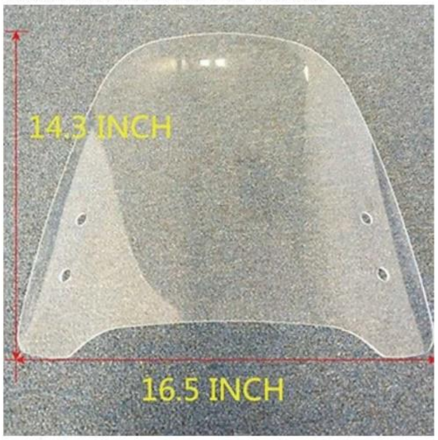
30 Amp Toggle Switch Polarity Reverse DC Motor Control - Momentary



Item specifics

Condition:	New: A brand-new, unused, unopened, undamaged item in its original packaging (where packaging is applicable). Packaging should be the same as what is found in a retail store, unless the item is handmade or was packaged by the manufacturer in non-retail packaging, such as an unprinted box or plastic bag. See the seller's listing for full details. See all condition definitions	Type:	Wire
Wire+Type:	communications,+telephone	Switch+Type:	Toggle+Switch
Brand:	GAMA Electronics	Manufacturer:	square+d
MPN:	28PR-MOM	Connector+Type:	locking+connector
UPC:	851029006098		

CLEAR GY6 125CC 150CC SCOOTER MOPED DIRT BIKE MOTORCYCLE WINDSHIELD SCREEN VISOR



Product Description

This Mini Bike Parts, Scooter Parts Unlimited, Brand New Gy6 Scooters, Moped, Motorcycle

Full Size Windshield 125cc 150cc - **Includes Hardware**

Easy Structure, Easy Installation. Including A Full Set Of Installation Parts, Not Require Any Additional Parts.

Feature

- Condition: New Brand
- Color: Clear
- Material: PMMA
- Dimension Approx: **14.3" (HEIGHT)X 16.5" (WEIGHT)**
- Universal Fits For Most Motorcycles With **6mm Thread**

Specifications

- In Stock For Fast Shipping With Tracking
- **Fitment: 125CC 150CC SCOOTERS, MOPEDS, MOTORCYCLES**

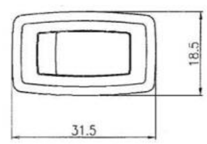
Switch

GB Gardner Bender

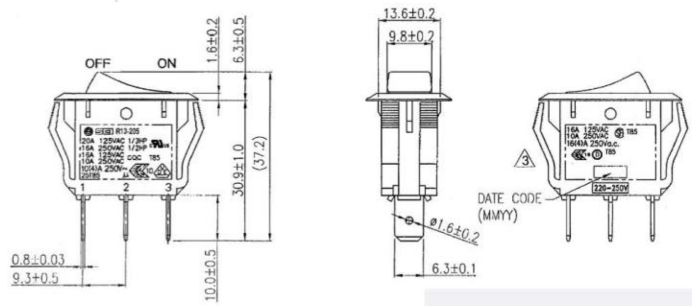
GSW-42

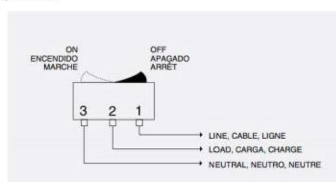
Rating	20A 125VAC 1/3HP 16A 250VAC 1/2HP 16A125VAC 10A250VAC CQC T85 16(4)A250Va.c T85 16A125VAC 10A250VAC T85 10(4)A 250~ 25T85	Mounting Hole	Circuit Diagram
Contact Resistance	50m ohm Max.		
Insulation Resistance	DC 500V 100M ohm Min.		1 2 3 R
Dielectric Strength	AC 1500V 1 minute		R=150K ohm
Operation Temperature	-25°C ~ 85°C		
Switch Function	3P SPST ON-OFF (Illuminated)		

Thickness	X	Y
0.75...1.25	27.6-0.1	13.8+0.1
1.25.....2	27.8-0.1	13.8+0.1
2.....3	28.0-0.1	13.8+0.1



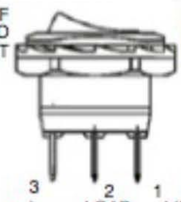
Material:
Frame: Black, Nylon 66
Actuator: Red, PC
Printed: None





www.gardnerbender.com | N85 W12545 Westbrook Crossing | 800.624.4320 | tech.support@gardnerbender.com

16 A 125V AC / 10 A 250V AC



FEATURES
- .187" blade terminal
- .787" diameter recommended mounting hole

CARACTERÍSTICAS
- 4.75mm terminales de hoja
- 20mm de diámetro agujero de montaje recomendado

CARACTERISTIQUES
- 4.75mm borne à lame
- 20mm recommandé diamètre trou de fixation

CAUTION / PRECAUCION / ATTENTION

Use only on circuits rated equal to or below ratings listed. Turn off all power before working on a circuit. Always conform to electrical codes.

Use sólo en circuitos de corriente con capacidad nominal igual o menor a la especificada. Desconecte la energía eléctrica antes de trabajar en un circuito. Respete siempre todos los reglamentos eléctricos locales.

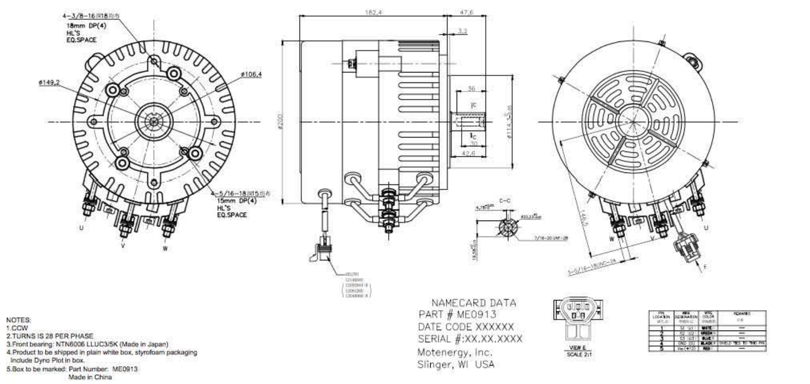
A n'utiliser que sur des circuits dont la valeur nominale est égale ou inférieure à la valeur nominale spécifiée. Couper entièrement le courant avant de travailler sur un circuit. Toujours se conformer aux codes électriques locaux.

WARNING: This product contains a chemical known to the State of California to cause cancer and birth defects, or other reproductive harm.

Milwaukee, WI 53209
www.gardnerbender.com
ZJ3759 1214
Made in China/
Hecho en China/
Fabriqué á Chine

0 32076 92017 3

Motor



Product Description

Output Power of 12 KW Continuous, 30 KW Peak (at 96 volts)

Designed for long life. No brush maintenance. The motor is 92% efficient at voltages between 24 to 96 VDC. Continuous current of 125 amps AC (180 Amps DC into the motor control). This is a 3-phase, Y-connected Permanent Magnet Synchronous Motor with an axial air gap and 3 Hall sensors at 120 degrees electrical timing. It has two stators with a rotor in the center.

1) This is a 4 pole motor (8 magnets). 2) The Phase to Phase winding resistance is 0.013 Ohms. 3) The maximum recommended rotor speed is 5000 RPM. 4) Voltages from 0 to 96 VDC input to the control. 5) Torque constant of 0.15 Nm per Amp 6) The Inductance Phase to Phase is 0.10 Milli-Henry with a 28 turns per phase. 7) Armature Inertia is 45 Kg Cm Squared. 8) Continuous current of 125 Amps AC (180 Amps DC into the motor control). 9) Peak current of 420 Amps AC for 1 minute (600 Amps DC into the motor control). 10) Weight of 35 pounds. 11) Peak Stall Torque if 90 Nm. 12) This is an Open Frame, Fan Cooled motor.

Includes temperature sensor.

Kelly KBL Brushless Motor Controller User's Manual

Devices Supported:

KBL24101X	KBL36101X	KBL72601E
KBL24151X	KBL36151X	KBL96151
KBL24221X	KBL36221X	KBL96201
KBL24301X	KBL36301X	KBL96251
KBL48101X	KBL72101X	KBL96351E
KBL48151X	KBL72151X	
KBL48221X	KBL72221X	
KBL48301X	KBL72301X	
KBL48401E	KBL72401E	
KBL48501E	KBL72501E	

Rev.3.3
Dec. 2012

Chapter 2 Features and Specifications

2.1 General functions

(1) Extended fault detection and protection. The LED flashing pattern indicates the fault sources.
(2) Monitoring battery voltage. It will stop driving if the battery voltage is too high and it will progressively cut back motor drive power as battery voltage drops until it cuts out altogether at the preset "Low Battery Voltage" setting.
(3) Built-in current loop and over current protection.
(4) Configurable motor temperature protection range.
(5) Current cutback at low temperature and high temperature to protect battery and controller. The current begins to ramp down at 90°C case temperature, shutting down at 100°C.
(6) The controller keeps monitoring battery recharging voltage during regenerative braking, progressively cutting back current as battery voltage rises then cutting off regen altogether when voltage goes too high.
(7) Maximum reverse speed is configurable to half of max forward speed.
(8) Configurable and programmable with a host computer though RS232 or USB. Provide free GUI which can run on Windows XP/2000, Windows 7 and Vista(recommend using Kelly Standard USB To RS232 Converter).
(9) Provision of a +5 volt output to supply various kinds of sensors, including Hall effect type.
(10) 3 switch inputs which are activated by connection to Ground. Default to throttle switch, brake switch and reversing switch. Closing to ground is to activate.
(11) 3 analog 0-5V inputs that default to throttle input, brake input and motor temperature input.
(12) Pulsed reverse alarm output.
(13) Main contactor driver. Cutting off the power if any fault is detected.
(14) Current meter to display both drive and regen current. Save shunt!
(15) Configurable boost switch. Enables the maximum output power achievable if the switch is turned on.
(16) Configurable economy switch. Limits the maximum current to half if the switch is turned on.
(17) Maximum reverse power is configurable to half power.
(18) Enhanced regen brake function. A novel ABS technique provides powerful and smooth regen.
(19) Configurable 12V brake signal input, instead of motor temperature sensor.
(20) Optional joystick throttle. A bi-symmetrical 0-5V signal for both forwarding and reversing.
(21) Configurable motor over-temperature detection and protection with the recommended thermistor KTY84-130.
(22) 3 hall position sensor inputs. Open collector, pull up provided.
(23) Optional CAN bus.
(24) Optional supply voltage 8-30V.

Caution! *Regeneration has braking effect but does not replace the function of a mechanical brake. A mechanical brake is required to stop your vehicle. Regen IS NOT a safety feature! Controller may stop regen, without warning, to protect itself or the battery(it won't protect you!).*

2.2 Features

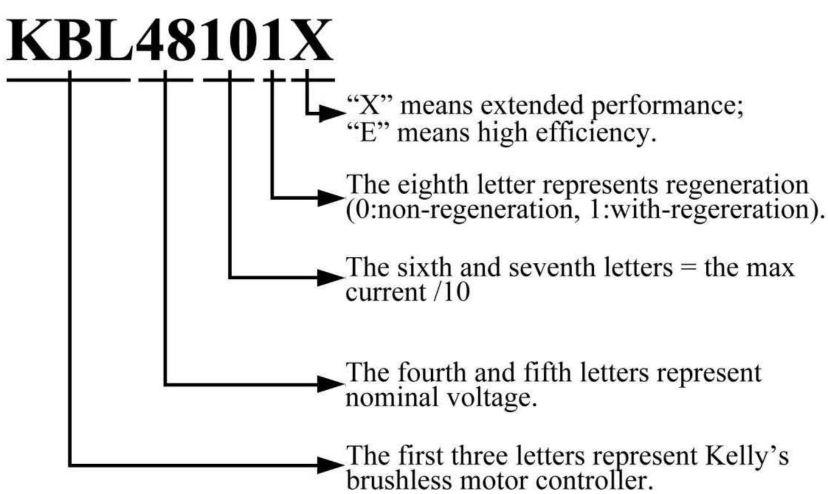
1) Intelligence with powerful microprocessor.
2) Synchronous rectification, ultra low drop and fast PWM to achieve very high efficiency.
3) Electronic reversing.
4) Voltage monitoring on 3 motor phases, bus, and power supply.
5) Voltage monitoring on voltage source 12V and 5V.
6) Current sense on all 3 motor phases.
7) Current control loop.
8) Hardware over current protection.
9) Hardware over voltage protection.
10) Support torque mode, speed mode, and balanced mode operation.
11) Configurable limit for motor current and battery current.
12) Low EMC.
13) LED fault code.
14) Battery protection: current cutback, warning and shutdown at configurable high and low battery voltage.
15) Rugged aluminum housing for maximum heat dissipation and harsh environment.
16) Rugged high current terminals, and rugged aviation connectors for small signal.
17) Thermal protection: current cut back, warning and shutdown at high temperature.
18) Configurable 60 degree or 120 degree hall position sensors.
19) Support motors with any number of poles. Up to 40,000 electric RPM standard. Optional high speed 70,000 ERPM, and ultra high speed 100,000 ERPM.
    (Electric RPM = mechanical RPM * motor pole pairs).
20) Support three modes of regenerative braking: brake switch regen, release throttle regen, 0-5V analog signal variable regen.
21) Configurable high pedal protection: the controller will not work if high throttle is detected at power on.
22) Current multiplication: Take less current from battery, output more current to motor.
23) Easy installation: 3 wire potentiometer can work.
24) Remote fault code LED driver.
25) Current meter output.
26) Standard PC/Laptop computer is used to do programming. No special tools needed.
27) User program provided. Easy to use. No cost to customers.

2.3 Specifications

•Frequency of Operation: 16.6kHz.
•Standby Battery Current: < 0.5mA.
•5V Sensor Supply Current: 40mA.
•Controller supply voltage range, PWR, 8V to 30V for KBL 24V controllers. 18V to 90V for KBL controllers rated equal or lower than 72V. 18V to 120V for 96V controllers.
•Configurable battery voltage range, B+. Max operating range: 18V to 1.25*Nominal Voltage for controller rated equal or higher than 36V. 8V to 30V for controller rated equal 24V.
•Standard Throttle Input: 0-5 Volts(3-wire resistive pot), 1-4 Volts(hall active throttle).
•Analog Brake and Throttle Input: 0-5 Volts. Producing 0-5V signal with 3-wire pot.
•Reverse Alarm, Main Contactor Coil Driver, Meter.
•Full Power Operating Temperature Range: 0˚C to 50 ˚C (controller case temperature).
•Operating Temperature Range:-30˚C to 90 ˚C ,100˚C shutdown(controller case temperature).
•Boost Current, 10 seconds: 150A-550A, depending on the model.
•Motor Current Limit, 1 minute: 100A-500A, depending on the model.
•Motor Current Limit, continuous: 60A-200A, depending on the model.
•Max Battery Current : Configurable.

2.4 Naming Regulations

The naming regulations of Kelly BLDC motor controllers:



3.2.2 Wiring of BLDC Motor Controller

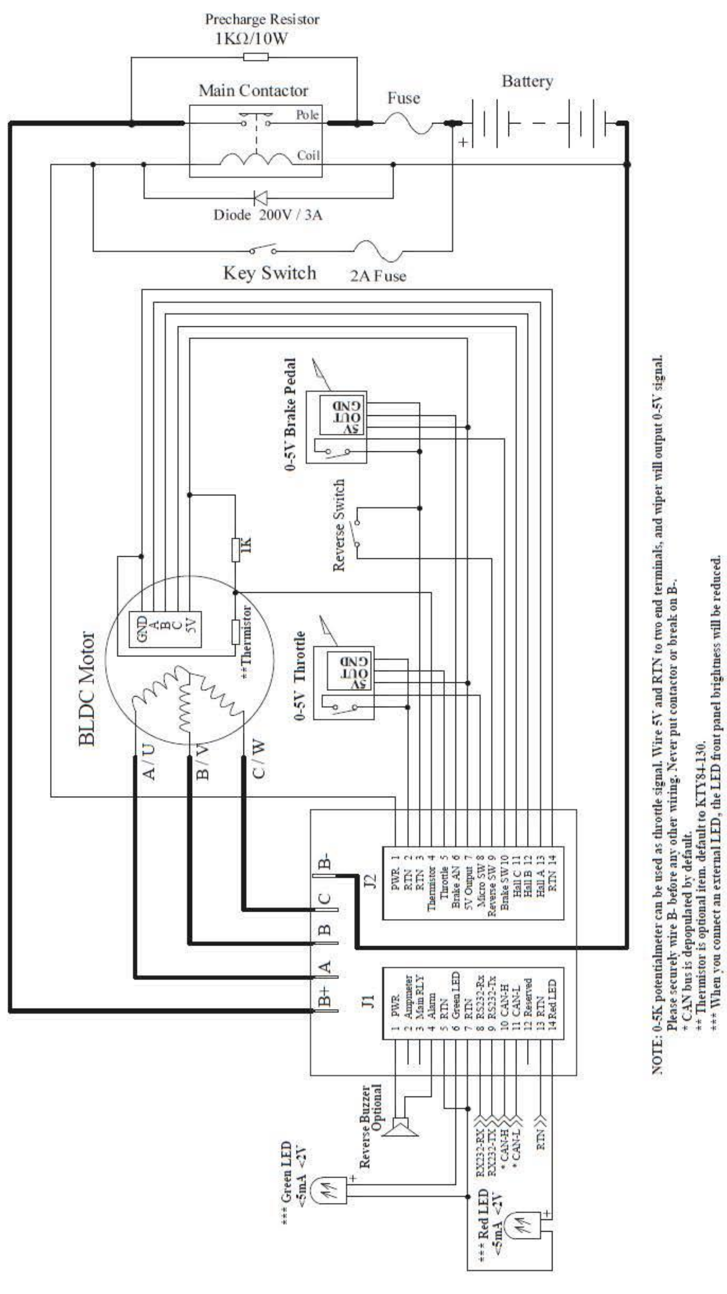


Figure 7: Standard Wiring for Controllers Rated Equal or Lower Than 120V.

Appendix G: Driveshaft Calculations

Driveshaft Calculations

Knowns:

Peak Motor Torque: 70 ft-lb
Peak Continuous Motor Torque: 288 in-lb
Peak Strength of 304 Stainless Steel: 95,000 psi

Calculations:

Calculating for fatigue strength of ¾-inch 304 stainless steel:

$$S_e = k_a k_b k_c k_d k_e k_f \cdot S_e'$$

$$S_e' = \frac{1}{2} \cdot S_{ut} = \frac{1}{2} \cdot 95{,}000 = 47.5\ ksi$$

$$k_a = a = 1.34 \cdot 95^{-0.085} = .91$$

$$k_b = b = .879 \cdot .75^{-.107} = .91$$

$$k_c = c = .59$$

$$k_d = d = 1$$

$$k_e = e = .89$$

$$k_f = f = 1$$

$$S_e = .91 \cdot .91 \cdot .59 \cdot 1 \cdot .89 \cdot 1 \cdot 47.5 = 20.6\ ksi$$

Calculating for max force applied using peak continuous motor torque value:

$$\tau_{max} = \frac{T \cdot r^2}{\frac{\pi}{32} \cdot d^4} = \frac{288 \cdot (\frac{.75}{2})^2}{\frac{\pi}{32} \cdot .75^4} = 5215.19\ psi$$

The ¾-inch 304 stainless steel gives a factor of safety for the driveshaft to be about 4.