Electric power for boats

Introduction

There is an increasing number of electric boats in the Club including, of course, a thriving Club 500 activity. There is a complete spectrum of the types of boats used within the Club – from the modified ready-to run boats, out-and-out racers and a good number of scale boats. This article on electric power is by no means complete – books have been written on the subject – but the intention here is to provide a few general hints for those who are relative beginners, and who perhaps just want to gradually up-grade a standard off-the-shelf model, to those who are more ambitious and might benefit from a few tips on construction techniques if they want to build something from scratch. In general, the electric scene is developing quite quickly and it's likely that some of the comments and ideas in this article will look rather old-hat in a couple of years time.

Scale electric boats are not included specifically in this article mainly because, generally speaking, such boats need to conform to the recommendations of the original designer, although minor modifications might be made to improve the power pack, for example with the use of more up-to-date components.

Almost-ready-to-run (ARTR) boats

There is a wide range of entry-level electric boats available, usually catamarans or mono-hulls. They are great fun-boats with reasonable performance at an affordable cost, and examples are often seen on auction sites. However, the quality of the components is what one might expect from boats made to a price, in particular the quality of the material and the actual form of the hull is usually somewhat limiting to performance and longevity. Nevertheless, a good deal of testing has been undertaken on such boats, so they do perform pretty well straight out of the box. Not surprisingly there are several suppliers who will supply up-graded components, such as better propellers, more powerful and responsive servos, electronic speed controllers (ESCs) with improved performance, more robust prop-shafts, more efficient motors, better wiring and connectors, and so on. When considering such up-grades it is a good idea to think carefully about what you are trying to achieve, for example: perhaps more speed, more reliability, or a combination of both. Some research is often needed – however, copying a setup that is known to work is generally a good initial strategy. Even with a few of such modifications ARTR boats can achieve excellent – dare I say electrifying – performance with a modest outlay.

Conversions from glow or petrol to electric power

There are many sports or racing boats, originally designed for glow or petrol power, that have excellent performance on the water. However, in general, the modified electric boat should have the potential for going significantly more quickly than their petrol or glow motor counterparts. Inspection of the speed records bear this out – but the drawback of extreme speed is a distinct lack of runtime.

The advantage of modifying an existing hull is that the handling characteristics of such a hull are likely to have been well researched and so replicating the optimum centre of gravity, for example, might require a little experimention – usually by moving batteries around in the hull. Moreover, the materials used are likely to be much better (stronger) than the plastic derivatives used in commercially-available ARTR boats.

Whatever choice is made between a new, or existing, hull it is essential to ensure the water-tightness of the hull is achieved. It is traditional to install a radio box in a petrol boat – essentially because there is little to stop water entering the hull because the engine needs to breathe! On the other hand most scratch built electric boats tend to be constructed assuming that the hull can be completely watertight and therefore further waterproofing is largely an unnecessary complication. Of course, all things being equal this is a fair assumption, however in practice it is probably not as clear cut as all that. Water can enter the boat through the stuffing tube, or through cracks, leaky joints in cooling tubes, etc. or catastrophically through broken cooling tubes.

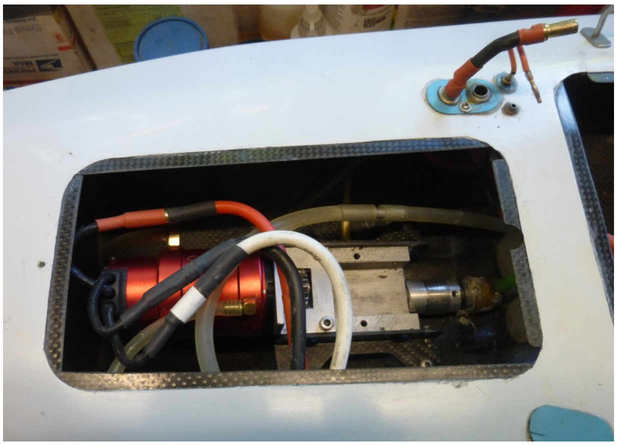

Fig.2 *and it goes like a rocket ...*

Fig.1 *A neat installation to convert a geared multi-boat to an electric racer, note the safety loop and external ESC arming arrangement*

Within the hull of an electric boat there are at least: a motor, an ESC, batteries, radio receiver and servo. A wet motor is usually rescue-able, some of the latest ESCs are essentially waterproof, LiPos will take a certain amount of water but the connections will corrode quicker unless completely dried out, radio receivers are very rarely waterproof and if wet will need to be carefully dried out, some servos are claimed to be waterproof, but most are not. Therefore, for a little extra work it is a good idea to enclose as many of the electronic components in a separate waterproof housing as possible. There are many radio boxes available as well as waterproof boxes used for keeping phones waterproof and the like, such as the commercial range of micro-Peli cases. Remember that wires entering and leaving such boxes need to be waterproof so care needs to be taken with electrical lead-throughs.

Connectors and wiring

With electrically powered boats the electrical resistance between the battery and the motor needs to be minimised and the wiring between the motor, ESC and battery needs to be as short as possible.

Minimising the resistance: is important because any resistance will create unwanted heat at high current flows, for example at a constant 100 amps, a resistance of just 1 milli-ohm will generate 10 watts of heat, so for a 6S pack with an internal resistance of 30 milli-ohms, this heat could amount to 300 watts when the battery delivers 100 amps.

High quality connectors will help to keep minimise the resistance of the power circuits. Although there are a number of different types of connector available probably the best is the bullet type. These come in a range of diameters from 2 mm to 10 mm, they are usually gold-plated and the plug contacts are often in the form of a series of multiple fingers bearing on the inner diameter of the mating socket. For plugs up to 5.5 mm diameter there is often a perforated spring around the central plug, for larger sizes the contacts are formed by slits in the body of the plug itself. It is not wise to flex contacts on such plugs as the material is frequently prone to fracture. If the plugs loose their spring it is best to replace the connector. For convenience, the XT series of connectors is useful because the connectors are supplied as a pair in a holder which makes mating the connectors easy, and assuring the correct polarity. Whatever plug and socket arrangement is chosen make sure that there is no confusion about mixing polarities so colour coding and choosing a convention for plugs and sockets is very important. The XT connectors come with 30, 60 and 90 amp ratings, although there are 120 and 140 amp types of the same general design available as well. But which size of connector to choose? It really depends on the continuous current you expect the batteries to supply. In general terms, the expected current flow determines the sizes of the connectors and the wire. Using thick wire with small connectors will cause considerable problems with making proper connections, using thin wire with large connectors will be equally problematic because the wires are not in good contact with the connectors and solder is not a great conductor.

Current range (A)	50-100	100-150	150-200	200-300
Wire size (AWG)	10	8-10	8	6 or 2x8 AWG
Connector (mm)	5.5	5.5-6	8	10

Table 1 *Approximate wire sizes and bullet-style connector sizes for constant running. Note AWG stands for American Wire Gauge – it is the most common way of designating the size of wires for electric boat applications.*

Fig.3 *A mixture of connectors, on the left are 4 mm which come in different lengths, a 5.5 mm and a 2 mm*

Fig.4 *Bullet style connectors, from top to bottom 5.5 mm, 6 mm, 8 mm (a heavy duty version), 8 mm and 10 mm*

Sometimes it is necessary to form “Y” connections in the wiring arrangement, for example for running two sets of batteries, or adding a small wire to connect voltage sensors or spark arrestors. The best way to achieve such a connection is to pare back the main wires, twist them together and bind them with fine wire, separately tin the bound wires and the connector, bring the two components together and then heat until a solid bond is achieved. However, do not underestimate how much heat this process will take. As a guide, twisting two 8 AWG wires and then tinning the resultant bond can be achieved with a 200 W iron, but it would be a struggle to bond the assembly into a connector. Heat applied using a small gas torch is a way to do this, but use some form of heat-resistant support for the wires is required, so that the wires and connector are well aligned, and for the insulation so that it is not damaged. Obviously, bonding smaller wires require less heat, but do not use too small an iron as a dry joint, not only has a high resistance but it creates electrical noise as well, and will likely fail because high currents will pass through those few wires that are in good contact with one another.

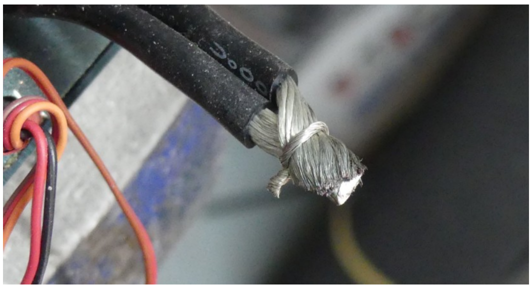

Fig.5 *Initial setup to join two 8 AWG wires, binding wire can be trimmed later*

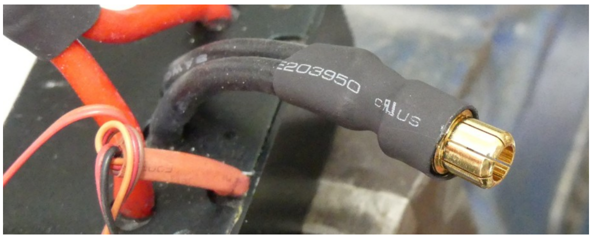

Fig.6 *Heat shrink to support the joint and 10 mm male connector*

Short wiring is a requirement of a good electrical setup, primarily to maintain the performance of the ESC, it is important to keep the wires between the ESC and the batteries as short as possible. The recommendations of the ESC manufacturer should be followed, sometimes supplementary capacitors are recommended to reduce the influence of connecting wires. The technical reasons for this are not simple but excessive inductance of long wires, the dynamics of the changing currents flowing when the throttle is varied, and capacitances in the batteries, can have an adverse effect on the characteristics of the ESC.

Batteries

There are many different types of batteries in use in models. Although some of the requirements for particular types of battery might be different for boat, aircraft or car applications, the basics are very much the same and we are lucky in the Club to have experts who can advise on more or less any special requirements and the appropriate treatment of batteries for different applications. So, if in doubt, seek advice.

There is such a lot written about batteries that this short article cannot do justice to all the finer points, so this is a bit of a whistle-stop tour. Remember, although there is a great deal of information on the web, some of which is correct and helpful, but some is just plain wrong and/or misleading – so please take care to choose an authoritative source for information to dig into.

Nickel hydride (NiH): although this type of battery was regularly used for powering racing boats, their main application now is powering servos and the receiver. Such batteries are happy being charged slowly or quite quickly depending on the application, but always take care to follow the manufacturers guidelines. Sometimes NiH batteries can give a false impression that they are fully charged, when in fact, they will discharge quite quickly under modest loads. So, it is worth periodically checking them by discharging the battery and checking that its capacity is what you expect – most chargers offer this option.

Lithium iron phosphate ($LiFePO_4$ or usually just LiFe): such batteries have better technical characteristics than NiH and lithium polymer (LiPo), however they are more expensive than LiPos and are rarely used as the power source in boats. Their main use is in radio boxes, and in specialist fields, such as providing power for model jet engine controls where reliability is very important. It is important to charge such batteries according to the manufacturers recommendations, but a charging rate of 1C (C = the capacity of the battery, for example for a 5 Ah battery, C = 5) is quite suitable in most cases, but do not be tempted to over-charge the battery.

Lithium Polymer (LiPo): this type of battery is now used almost exclusively for powering model boats, cars and aircraft. A lot is said about how safe they are. In my opinion, they are as safe as any other type of battery, provided:

- the batteries are charged correctly (using a "reputable" computer-based charger and ideally being watched over). Battery mishaps usually occur when charging, so charge batteries at a rate known to be optimum for the battery – normally 1C. It may be possible to charge at a higher rate with some of the most modern batteries, but make sure that this recommended by the manufacturer and you need to do it. LiPos ought not to be charged at a low rate as this will adversely effect the life of the battery. Never charge LiPos in the NiH mode as this will risk an accident.
- handled safely (charge level reduced to storage charge, when not in use for extended periods, etc.) and,
- mounted securing in a boat correctly, usually using Velcro fastenings, and/or straps. Leave some room for the batteries to expand, which they might do if stressed by high-current draws. It is a good idea to place a physical stop to reduce the possible forward movement of the battery in the event of a crash.

It is vital to remember that LiPos can deliver their energy – in the worst possible case a dead short – at an alarming rate, so always cover live connectors during charging and use. It is worth mentioning that carbon fibre is not an insulator so treat it like a metal. Be aware of the sparks emitted by high S (probably 5 and above) cells. There are two schools of thought on sparks:

- sparks are bad – they damage connectors on contact and can spray tiny metal particles in all directions. Such problems can be reduced by using "sacrificial" connectors to make the initial contact, but remember to cover all "live" connectors at all times.
- sparks are good – a fat spark indicates that the capacitor in the ESC is functional.

Sparks can be eliminated by making the initial contact between the battery and the ESC using a resistor which allows the system to slowly reach working voltage slowly and then removing the resistor and connecting the power leads. The same function can be achieved using a connector with a built-in resistor.

As time goes on new battery materials come into use, for example so called "high-voltage" LiPos are becoming available, for which the cells can be charged safely to 4.35 V as opposed to 4.2 V for the "regular" LiPos. Some radio receivers, servos and chargers can work with such batteries, some definitely cannot, so follow manufacturers' recommendations, or it could be expensive.

LiPos in racing applications have a life, measuring the internal resistance (IR), or equivalent series resistance (ESR), of a battery with an appropriate ESR meter, or by using the display on some high-end chargers are good ways of assessing the state of a battery. It is difficult to put precise numbers on the ESR values, but 3 milli-ohms/per cell would be reasonable, and 6-8 milli-ohms/per cell would be considered time to think about buying some new batteries. In addition, the charging voltage cell-to-cell should not differ by no more than a few tens of milli-amps during the charging sequence. Ideally, if you can keep a log of the IR of the batteries you use you can track the change in performance over time. For racing, high-end (expensive) batteries have very low IRs and all the cells have very closely matched IR values, and they are expensive, but carefully looked after are worth an investment! If you wondered why your boat is slower than expected perhaps ageing batteries might be a possible cause.

Electric boat design

Most boat designs can be powered by either electric or petrol/glow, but electric power is particularly useful when space in a hull is extremely limited and a scale appearance is desired to be maintained, or where maximum speed is required for a short period. Electric setups are much more flexible than petrol because major components can be located in a range of locations within the hull. In addition, multi-engine setups are much easier with electric power, especially for catamarans. However, the design process for the power plant of an electric boat is really complex, because there are so many variables. As an example of this complexity, just considering the choice of motor will reveal that even for the same physical size of motor there are widely different kV values available (kV is essentially the number of revs when 1 volt is applied to the motor) and even the same kV motor can be obtained with different windings, which in turn have different characteristics.

Probably the most important factor in an electric boat design is to know how to achieve the intended performance. Knowing your requirements, such as how fast you would like to go and for how long with a particular size of boat are the obvious starting points. From there establishing the power of the motor required and from that the number and size of batteries needed. With some research of other boats that perform in a similar way, a choice of suitable candidates should become clearer and from that a prototype can be built. Once built the prototype can be run and its performance monitored. The current drawn by the motor, speed and the rpm of the rpm are the key parameters to be measured to see if progress towards the desired performance is being achieved. An ESC with a built-in logger, which can log: voltage, current and motor revs are available, stand-along loggers are also available but have been largely superseded by loggers integrated into the ESC. A number of radio control sets have a telemetry capability, whilst this is useful the facility is usually only available on high-end sets and the separate units to measure each parameter are quite expensive. Alarms to indicate low battery etc. that work in real time are of course useful, but there are usually safeguards incorporated into the ESC software. It is not a good idea to run a boat only to discover that the solder in the connectors has melted, or the batteries have puffed up, or the ESC no longer functions!

Safety is important for electric boats, the batteries need to be capable of disconnection from the motor, ideally in all boats, but essential in racing boats. Although most ESCs have an arming switch it is not a complete guarantee that the motor will not fire up unexpectedly. Traditionally, a so-called safety loop is used. This is simply a connection in the main power line that can be broken, usually by pulling a pair of connections apart which are mounted on the deck of the boat and easily accessible to a rescuer. There is very little performance penalty with this approach in terms of added resistance – may be at worst a few milli-ohms – whereas an automotive battery isolation switch might have a resistance of 20 milli-ohms or so when closed, which represents a significant voltage drop at high currents.

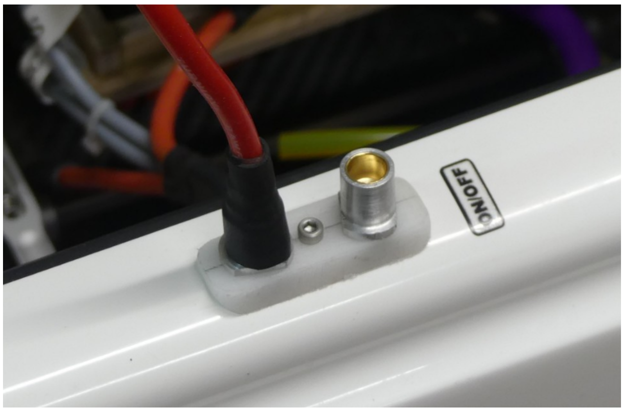

Fig.7 A s*afety loop provides an essential way of disconnecting the power between the motor and the battery. Here a connector is supported in an aluminium holder and a nylon support, the gold-plated connector provides the best electrical contact and therefore least power loss*.

Acknowledgements

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