***F&B's Workshop & Fitting Out** section is designed to assist readers with technical or fitting out problems. Typical matters include dialogue on re-powers, upgrading electronics, prop selection and use, matters of trim & performance, maintenance etc. If we can't help, we'll find the best person on the subject for you, and relay their views.*

Home Work Shop & Fitting Out

Your Boat's Wiring:

How Not To Stuff It UP!

Over some years, as I have tested and corrected sundry wiring problems in vessels I have sometimes been amused, sometimes appalled at the ignorance of basic electrical theory displayed by wiring contractors.

The grave risks to which vessel owners expose themselves, their friends and families by this ignorance can be quite frightening. You might already be thinking, hey, that's all very well but I'm an accountant or a salesman, not a technician!

How can I be expected to know? Let me hasten therefore to reassure you, it's not rocket science – mostly basic common sense, and if you exercise the brain just a little more you can be much better prepared for survival at sea!

Let's have a look at some practical situations recently discovered during a vessel rewire, and include just a little theory that reinforces my descriptions. Note that this is a large and complex subject, and the following details are necessarily abbreviated, basic and indicative in nature.

While based on common and published knowledge, they are naturally a reflection of my personal views. If in doubt you should undertake appropriate research. Here endith the disclaimer!

I will consider firstly the subject of electrolysis and corrosion in general, and progress from there to various facets of wiring and fitting that will help to keep you afloat and comfortable.

The electrical systems in a boat are working in a very hostile environment and in my view, paraphrasing a common mantra, there are three critical factors to minimize in a marine environment – corrosion, corrosion and corrosion! In considering these matters I am mostly concerned with operating in salt water, arguably the most common environment for boating in this country and the most likely to damage your vessel.

Now, salt is great stuff! You can float in it more easily, you can enhance the flavor of your food with it, you can preserve food, you can even clean your teeth with it! Although it has many desirable domestic and industrial qualities, it hates boats! More specifically, it most particularly hates the metal bits in boats, and it is a fact of life that if you run a boat in salt water, many bits of it will corrode. Alarmingly quickly in fact, if galvanic action is initiated in the various metals within your boat, or even between your boat and a neighbor in the Marina! Essentially, any dissimilar metals immersed in an electrolyte (read "salt water") form an electrical potential or "potential difference", or voltage – that is, a battery!

Different metals create different potentials between them, but all metal combinations produce some potential difference, and a "Galvanic Series" table indicates which one is the "cathode" in relation to the other, and hence which one is (relatively speaking) the anode. The anode is gradually dissolved by the current flow (In fact impurities in metals can even generate these potentials internally, with similar results). The zinc anodes on your motor and hull are designed to be eaten away, or "sacrificed" to the galvanic God, rather than chewing holes in your hull.

In addition to this chemical action, there may also be stray current corrosion which has similar effects, and often caused by loose connections or corrosion providing a difference of voltage potential, and therefore a path via the hull (immersed in salt) instead of its normal path. It generates the same result as above. Consequently, salt water just loves copper wire and stainless fittings on boats, and this provides us with some challenges to maintain their integrity and our safety. The battery switch terminal (Picture # 1 below) illustrates in part these

problems. Clearly it had been loose for some time, with current arcing apparent on the cable lug and washers, along with mild steel nuts which had rusted and were probably not very conductive by this stage. The isolation switch shown is an 'el cheapo", normally used in a vehicle or land based setting! With upwards of 170 amps drawn by starter motors on the engines in this vessel, there is no leeway to economize on heavy duty, waterproof switches with large terminals and stainless hardware.

The state of the battery boxes (Picture #2 below)

indicate the wiring technique (not!) utilized throughout this vessel – add-ons over many years by inexpert hands, generally under dimensioned for the current expected and not inspected or maintained.

It is always essential to get as much voltage at the working end of a cable as possible, particularly in the case of electric motors whose performance falls off rapidly with voltage. A generally accepted maximum voltage loss of 3% should be applied to all circuits you install, with an absolute outside loss of 10%. Many devices (incandescent lamps for instance) will work reasonably at a 10% loss of voltage, but then, why use incandescent when LED's are so cheap these days and use vastly less current with much thinner wire as the bonus? Use the 3% figure where at all practical for everything (tables are available in books on marine installations). Bear in mind that with heavy current devices like starter motors and windlasses the recommended cable sizes can be humungous - compromises may need to be considered.

For example, the cable run from starter battery to the bow anchor windlass in this vessel, an 8.5 metre Shark Cat, was about 7.0 metres. Positive and negative length therefore is 14 metres, and the 3% tables give a preferred cable size at 100 amps of AWG size 0 (or about 53mm squared. This is a comprehensive cable and, if you can get it tinned, is worth a King's ransom. The tables I have only go to 100 amps, but I have calculated what is required for the actual current when the windlass is UNDER LOAD (measured at 150 to 160 amps), and it comes out to between 4/0 and 5/0 AWG (107 to 135mm2). This is 2 to 3 times the cross sectional area of a vehicle battery cable - a small barge would be required just to carry it around!

Info Box: Wire Gauges

People measure wire in different ways - of course. Why make it easy? In the US they generally use the American Wire Gauge (AWG), while Europe (and us) mostly uses cross sectional area, or millimetres squared. Auto Electricians (and the industry) commonly use (as far as I can gather) the cross-sectional area including the insulation! Why I am not sure, but I think it comes back to the size cable you can poke through a hole! I stick to conductor only cross-sectional area because of the variability of insulation thickness. It does mean though that I have to revert to the tables to compare standards sometimes.

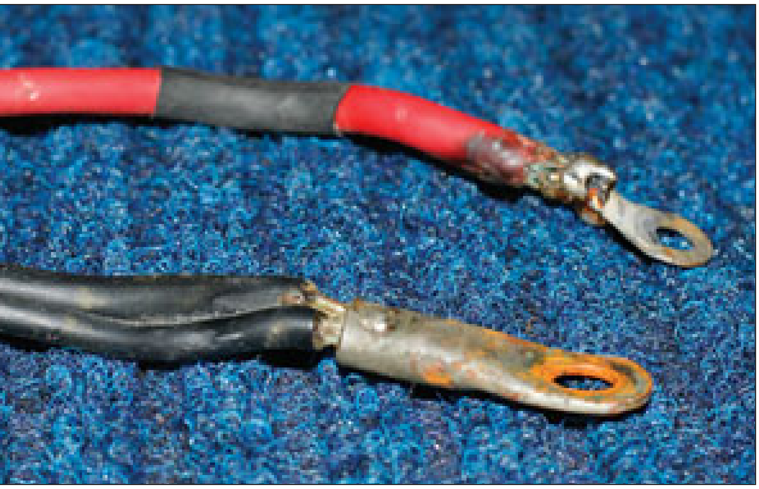
Mariners in general try and use the cheapest and most available parts and cable – it is a natural reaction to the high price of products designed to last. I am certainly guilty of it, and I bet you are too! The end result though is often less than satisfactory – look at the cable on the right in Picture # 3 below.

Looks ok? Looks heavy enough for a windlass? Well, it might be in some circumstances, but it measures as 7/032 cable (7 strands/0.032" diameter). This is usually electrician's type cable, generally used for power distribution in AC switchboards and the like.

As a winch cable in a static, vibration free environment - perhaps. Not a terribly suitable cable for marine use, which should have a large number of very fine conductors for flexibility and vibration stability, and preferably tinned for corrosion resistance.

Terminal lugs should be sealed end types, with an overlay of heat shrink material (preferably the glue filled type) to prevent water ingress and corrosion at the cable end. Picture # 3 above also shows the corrosive effect of moisture wicking along a cable inside the sheath oxidizing the copper as a prelude to corrosion – tinned wire resists this more successfully, but the real answer is total sealing, not a bit of insulation tape!

Clearly some compromise is called for, but you must remember, if less than recommended size cables are used the effect is higher resistance hence less volts available at the end, and greater heating effect on the cable. In terms of current carrying capacity of cables, this windlass cable was quite substantial, having a diameter of around 5mm and consequently an estimated cross sectional area of 19.6mm sq. Unfortunately, like all wiring in this vessel it appeared to be what the electrician had to hand, not what was ideal for the job. This rigid cable is prone to fracture by vibration, and it is a really mongrel thing to work with, more suitable for its intended use than in boats. Note in Picture # 4 (below) the fitting of two



cables (windlass and main bus to the breaker panels) with a hammered "crimp" and poorly soldered into the lug (commonly known as "cocky****"). Picture # 5 shows a comparison with perhaps a more suitable, albeit un-

tinned, cable.

Effective wiring practices dictate maintaining cable runs as short as possible, an adequate gauge cable for the current expected and appropriate terminations. The picture of a fuse holder terminal – Picture # 6 below is a

very good illustration of how not to do it.

Mounted in a battery box, it was not in a wet location, but certainly where it might get damp. It was feeding a sullage pump and the fuse had melted because of too much current for too long without enough to "blow". The reason became obvious when I handled the holder, the wire disintegrated in my hand. Damp had wicked up the wire and corroded it completely – current was probably flowing in one strand or so, with consequent high resistance and over-heating. The picture actually compares two fuse holder wires from the same battery box – the one above, and another on its way to the same result. Maintenance on this vessel was not stringent!

This is probably worth emphasizing – inspection and maintenance is a continuous process on a boat- there is simply no way you can ignore for too long the effects of moisture and salt. Don't "hide" connections and terminations where they are difficult of access, regularly poke and prod to check security, keep an eye out for rust or corrosion and ***try and determine why.***

Now, you already know the story, about life not meant to be easy, and there is a great deal more to cable

Info Box: Resistance of Cables

Cables have inherent opposition to the flow of current, termed resistance, and this resistance has the effect of "dropping" voltage across it. So, if you measure a voltage of X volts across your battery, you will always get something less across your load (light, radio etc) when current flows. This volt drop is proportional to the battery voltage and the resistance of the cable. The trick is to choose cable that has little resistance and therefore maintains the maximum voltage available for your load. If there are de-rating factors such as excessive ambient heat, ducting or bundling etc, then you need to adjust the cable dimensions so it can safely handle the current in the circuit. For example, a cable with a cross sectional area of 16m2 might safely handle 90 amps outside an engine space, but will be de-rated to only 67 amps or so in an engine space at a 70 degree insulation rating (from ISO standards).

dimensioning than this! Some things to consider are de-ratings for “bundling” of cables, location inside or out of conduits, temperature ratings of insulation and consequent amp capacity of cables, ambient temperature (engine room or outside), cable construction (strand number, material etc) and so on. A primary consideration though is the volt drop, and you should consider this first and then “de-rate” from there. See the info box (bottom left) on voltage measurements.

How do you find the right sized cable? Well, the easy way is from published tables, but there are formulae that can be used. You may need to research the subject, but a sample of a suitable table of a 3% volt drop is in Figure # 1. You will note that cross sectional area requirements increase dramatically with distance and current.

Info Box: Guide to conductor sizes in mm^2 for current & length

Current	Length of conductor from source and back in metres						
	3.0m	**4.6m**	**6.0m**	**7.6m**	**9.1m**	**12.2**	**15.2m**
5	0.8	1.3	2.1	3.3	3.3	5.3	5.3
10	2.1	3.3	5.3	5.3	5.3	8.3	13.3
15	3.3	5.3	5.3	8.3	8.3	13.3	13.3
20	5.3	5.3	8.3	13.3	13.3	13.3	21.2
25	5.3	8.3	13.3	13.3	13.3	21.2	21.2
30	5.3	8.3	13.3	21.2	21.2	21.2	33.6
40	8.3	13.3	13.3	21.2	21.2	33.6	33.6
50	13.3	13.3	21.2	33.6	33.6	33.6	33.6

NOTE: These are cross-sectional area measurements, NOT cable diameter.

Readers should be able to see the problems with the terminal in Picture # 7 below, which is the terminal from

the battery box above. You will note the “open end” style, where damp and corrosion can get started, the less than professional (and certainly inadequate) crimp on the insulation which looks like it was done with pliers or a cheap, light crimper and the complete disintegration of the cable at the entry point. While the cable would have corroded from the open ring end in due course anyway, the lack of heat shrink over the cable and terminal barrel inevitably increased the rate.

A solid and effective ratchet (or hydraulic) crimper is essential for these terminals, to crimp thoroughly without puncturing the insulation. Picture # 8 (next) shows some

common crimping tools. The one on the left is probably best avoided – it does not crimp successfully and is probably more useful as a sinker. Perhaps it might be used in a real emergency, as a temporary solution. It does have the advantage of being very light. The middle crimper is a ratchet type, generally useful for insulated type lugs and smaller solid lugs up to about 5 or 6mm diameter cable. The hydraulic press on the right is a modestly priced unit with different jaws inserted for different size cable. It is reasonably effective.

Ideally the lugs should be crimped once again over the cable insulation to provide some strain relief. Heat shrink tube with a inner lining of glue/resin is available, which is ideal for these situations, making a water and air tight seal. Like everything good, it is expensive!

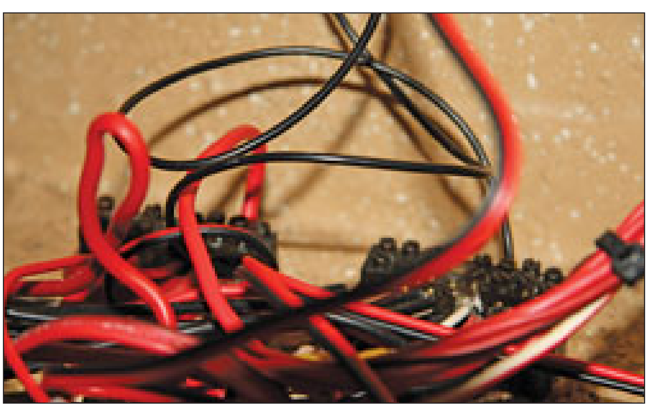
Some people will defend “tinning” the stripped portion of the cable in the terminal with a soldering iron prior to crimping, but my view is it can actually cause more problems. It is much harder to crimp a soldered cable, and the necessary pressure to “fuse” the terminal with the wire much greater, perhaps not possible with modest crimps. You are of course again combining two dissimilar metals with solder! In addition, the solder sometimes wicks back along the copper to the point of entry to the terminal, which can make this area brittle and prone to fracture. In general I find a good crimp is the best way to go.

Another (related) problem was uncovered when inspecting the reason for the sullage pump not operating (the disintegrated in line fuse holder wire). Looking at Picture #9 (over page) you will see an archetypal demonstration of how NOT to wire a high current pump.

This pump was hidden forward of a 350 litre fuel tank, and was consequently inaccessible for maintenance. The bright spark who wired it obviously decided that bilges were good places for electrician’s twist joint plastic terminals! In addition, this pump was wired to a switch on the wheelhouse console, and then back to the engine battery – a really considerable distance that needed a

better appraisal of suitable cable size. Similarly considerations apply to the macerator (rated at 20 amps and stall current at 70). I determined (from tables) that the recommended size for the current and distance in this instance was 13 to 21mm sq. to limit volt drop to 3%, or 5 to 8mm sq. for a 10% drop! I would probably have used 6mm sq. or, more likely, found some 13 or 16mm sq. giving me something in between 3% and 10% - like I said, mostly common sense.

In Picture # 10 (below)) the business end of the distribution cable from starboard battery to circuit breaker panels is shown, although it is probably difficult to work

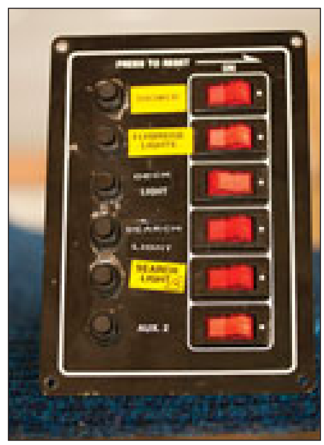


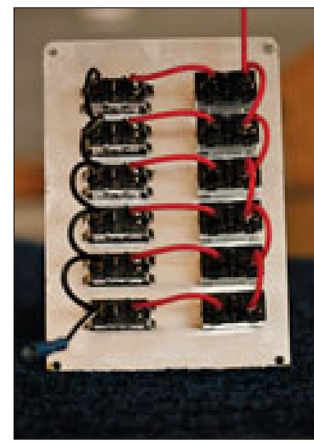
out which is which.

The electrician's termination blocks are unprotected, identifying the cables is impossible and the positive and negative bus are in close proximity. Clearly a fault waiting to happen and a nightmare to maintain or fault find.

Pics# 11 and 12 (above right) indicate the type of breaker panels you should seriously consider avoiding if you are trying for a professional installation!

Not only is the hardware necessarily on the economy side of useful, the pre-installed wiring on the breakers may not be suitably dimensioned for your circuits. For instance, you may have various reasonably heavy current devices fed from this panel, which might realistically all be





on simultaneously. In this instance there were 3 searchlights, a shower pump, bridge lights, deck lights and "Aux." Consider the positive "bus" on the back of this panel – looped in and out of each breaker, in what seems to be less than 1mm sq. wire!

The first loop carries all the current of all the devices! Not desirable, and a possible hazard. The best way around this is to pay more and buy a panel with a solid copper positive busbar. Or supply a separate busbar adjacent and feed each circuit individually from that.

Finally, and importantly, GROUNDING. I am only briefly discussing DC circuits here because AC grounding on boats is another matter altogether and is critical to personal safety – quality professional advice should be sought for AC installations.

Everyone seems to have a different "take" on grounding, its function and practical application.

The first thing to appreciate though is that the ground wire (negative generally) feeding your lights, radios, pumps etc, is a current carrying wire – it is the other "leg" of a DC circuit.

Secondly, current from the battery source via the

***positive leg of the circuit* will get back to the other terminal of the battery by any means it can!**

If the equipment is grounded internally to its metal case, and the case is bolted to, for instance, a metal hull, the "return" path is therefore via both hull and negative wire. You can imagine the net effect of a multitude of items grounded in this hap-hazard manner, with little earth return paths via various parts of the hull, all with varying degrees of potential "above ground" – perfect little stray current corrosion points, as mentioned above.

So, the answer is simply to ensure all electrical equipment with grounded case is insulated from the hull, and supply it with twin cable positive and negative, both above ground with the negative grounded only at a common busbar. The battery negative (and engine) is connected to this earth bar. This holds all grounds as near as possible to a common potential, and provides a low resistance return path to the battery.

Clearly, the connection from negative busbar to battery negative needs to be substantial to provide low resistance and high equipment terminal voltage. Again, this is where the cable and circuit breaker dimensioning considerations you make are critical.

Speaking of breakers, remember the breaker "tripping" current should be selected in relation to the dimension of the cable, not the equipment! The breaker is there to prevent excess fault currents over-heating the cable and hence generating a fire risk.

For example, if your cable is 16mm sq. insulation rated to 90 degrees, has a current carrying capacity ("ampacity") outside an engine space of 100 amps (derived from tables!), you might select a breaker of around 70 amps.

There is nothing to prevent you reducing the rating of the breaker to protect the equipment, but you need to consider the total current likely to be drawn in the cable, and whether individual equipment needs its discrete separate fuse protection. In general you would provide this for electronic type equipment in any case.

As I have mentioned, it is a big subject. Unfortunately it is one that very few people who "go to sea in boats" think about very much, evidenced by the deplorable, and possibly disastrous, state of wiring in this vessel. If this article has influenced a few mariners to cast a critical eye over their own boat, it will have achieved its purpose.

F&B

READERS: *This is quite a complicated subject for we normal people for whom the mysteries of the electrical wiring, circuits, bus bars and circuit breakers all seem part of a dark art designed to confuse - and worse, remain the source of never ending failures and expense. Mike has done a terrific job here, but as he says, it's a huge subject - and we are both keen to 'cut to the chase' and learn more from readers what they do - and don't understand. So don't hold back; email us your thoughts and queries, and we'll do our collective best to get them sorted ASAP.*