Design of Electric Drives for Boats

Because the power needed to supply the boat drive and auxiliaries – bilge pump, lights, TV &c – must all be carried in the battery, it is important to achieve the highest efficiency possible in converting electrical power from the battery into mechanical power used in overcoming resistance to the boat's motion through the water – ie drag.

Overall efficiency of boats with IC engines can be as low as 15%. Of the 85% of energy wasted, perhaps 1/3 goes in mechanical losses – seals, bearings, gears and gear oil (the latter can absorb several horsepower), and the balance in propeller losses. Because available energy is limited in electric drives, overall efficiencies of more than 50% are aimed at – roughly 80% motor and drive train and 63% propeller. The calculations of range given below are based on this assumption.

Design of the drive system should be taken in the following stages.

1. Hull Drag

It is essential to have a curve, or set of figures, giving the drag of the boat's hull against speed. The figures given by boat designers may be suspect – what equations have they fed into their computers? How often do they measure the drag of the hulls they design?

If in doubt, it is best to measure the drag of the hull to be fitted out by towing it – preferably without propeller – with a spring balance. Readings in lbs or kgs can be taken and then converted into force in Newtons.[1]

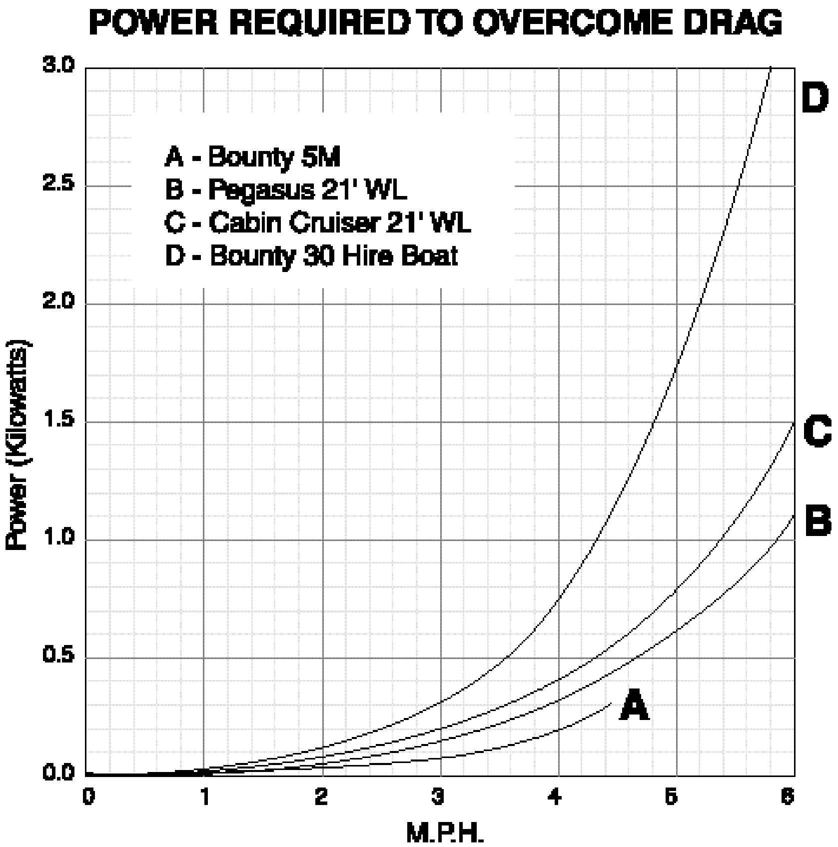

Fig 1 gives power in Watts required to overcome drag – derived from towing – for a typical 4-berth sailing boat and cabin cruiser, both with 21ft waterline length. A remarkable conclusion is that they

[1] To convert kgs to Newtons multiply by 9.81 (acceleration due to gravity); to convert lbs to Newtons multiply by 4.45 (2.2 lbs – 1kg).

need only about 1 Horsepower to drive them at 5mph (1BHP – 746W). Power requirement would rise very rapidly as the so-called hull speed is approached – about 6mph – and could easily be multiplied 4 or 5 times without much increase in speed – the extra power going largely into wave-making which can give the false impression that the boat is going faster!

2. Propeller Efficiency

A typical cabin cruiser with IC engine and 15% overall efficiency would require nearly 7 BHP to drive it at 5mph. This requirement could be increased, say, by three times if the speed is about 6mph, thus explaining why a 20 BHP engine might be fitted. If the speed were limited to 5mph, with overall efficiency of 50% a drive unit of about 2 BHP would be needed. This explains why an electric motor of 1.6 KW would be adequate for the job.

Excessive propeller losses are generally due to using too small a prop – perhaps 12” diameter on a 21ft sail drive or 14” on a 23ft launch. Optimum diameters might be up to 18” and 20” respectively, but compromises may be necessary in light of available draught and hull clearance. At these large diameters, sail drive propellers should be of the folding type, otherwise propeller drag when sailing will be too big. The general design approach is to fit as large a propeller as can be accommodated. Because of the relatively low power transmitted such propellers could be of lightweight construction with blades of plastic or hard rubber if desired, but these are not commercially available at present.

We have seen above that propeller efficiencies of at least 63% are required, though higher values are desirable as they will further put up the range of the boat. To achieve this, propeller slip will generally be below 20% **-** ie propeller speed (pitch x revs per hr, in MPH – pitch converted to miles!), about 25% greater than boat speed. A good propeller design procedure (or designer if affordable) will suggest optimum characteristics for the largest propeller to fit a given space on a boat with a specified drag curve.

This will determine, say, boat speed against propeller efficiency. If efficiency is less than 63% at the desired cruising speed, then the principal options are either to drop the cruising speed or live with the reduced efficiency and increase the battery pack.

Reducing cruising speed need not be disastrous, as power required varies roughly as the cube of the speed. Thus a reduction of say 1/4mph at 5mph (5%) reduces power needed by about 14%, increasing range by 16%.

Our own experience confirms the importance of propeller diameter as a key factor. For example increasing prop diameter form 18” to 19” on our electric outboards on Lord St Davids’ narrow boat increased efficiency by 10%.

3. Range and Battery Size

A typical 6 volt lead-acid battery (e.g., Oldham 3KQ11) has 175 Ampere Hour capacity at 5 hour rate[2] and 230AH at 20 hour rate and weighs 29.5 Kg. The specific capacity is therefore 6 x 175/29.5 = 35 Watt hours per Kg at 5 hr rate and 46.7WH/Kg, 20 hrs.

In practice, batteries should not generally be discharged to more than 80% of their full capacity, so this factor should be included in any calculations of available power.

As an example, taking the above figures, the size of battery pack needed for 20 hrs cruising of an auxiliary drive fitted to the sailing hull whose drag is given in Fig. 1, is worked out as follows. Overall efficiency is assumed to be 50%[3].

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[2] i.e. battery is fully discharged over 5 hours.

[3] Weight of battery pack = $\frac{\text{Total Watt Hours required}}{\text{Specific capacity x 80\%}}$

Speed	Mechanical Power (W)	Electrical Power (W)[4]	Total WH[5]	Battery Wt. Kg.	No. of Batteries	Approx. cost £
3.0	140	280	5,600	150	5	500
3.5	220	440	8,800	235	8	800
4.0	320	640	12,800	343	12	1200

If the range of 60-80 miles cruising is greater than required, the battery pack can be scaled down pro-rata. Cruising at higher speeds will reduce the range further. Good performance can be achieved without greatly reducing the range by having means of increasing battery voltage, and hence propeller rpm, in an emergency only – e.g. for braking or manoeuvring, or adverse currents.

It should not be necessary to increase rpm to cope with increased wind drag with a large diameter propeller as this should have sufficient "grip" and will thus take more power from the motor to overcome excess resistance without a big reduction of boat speed.

4. Mechanical Losses

These should be measured separately as far as possible and reduced to a minimum. Gear boxes should be avoided as far as possible as with normal oil they can easily absorb 500-600 Watts. If essential they should, if possible, be filled with the minimum of the lightest oil allowed with an additive such as Molybdenum Disulphide.

Deep Sea seals, properly adjusted, absorb only a few Watts – they are preferable to stuffing boxes. Cutless bearings also generally have low losses provided they are carefully aligned and adequately lubricated.

Summary

Essential steps in planning an electric drive are

1. Obtain hull drag

2. Minimise and estimate mechanical losses

3. Maximise and estimate propeller efficiency

4. Decide on cruising speed and calculate power required

5. Decide on range, choose battery type and calculate size of battery pack.

[4] Twice mechanical power at 50% efficiency.
[5] Electrical power x 20 – Watt Hours.